International Journal of Kinesiology & Sports Science
ISSN: 2202-946X
www.ijkss.aiac.org.au

Interventions to Promote the Development of Motor Performance Skills in Primary School Aged Children with Autism Spectrum Disorder: A Systematic Review and Meta-Analysis of Controlled Trials

Andrew Sortwell[1,2,3,*], Pedro Forte[3,4,5], Rodrigo Ramirez-Campillo[6], Kevin Trimble[7], Kylie Steel[8], Kate O'Brien[1], Henrique P. Neiva[3,9], Daniel A. Marinho[3,9], Ricardo Ferraz[3,9]

[1]*Directorate of Education and Research, Sydney Catholic Schools, Sydney, Australia*

[2]*School of Nursing, Midwifery, Health Sciences and Physiotherapy, University of Notre Dame Australia, Sydney, Australia*

[3]*Research Center in Sports Sciences, Health Sciences and Human Development, CIDESD, Covilhã, Portugal*

[4]*Higher Institute of Educational Sciences of the Douro, Penafiel, Portugal*

[5]*Instituto Politécnico de Bragança, Bragança, Portugal*

[6]*Exercise and Rehabilitation Sciences Institute. School of Physical Therapy. Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago, Chile*

[7]*National Catholic Education Commission, Sydney, Australia*

[8]*School of Health Sciences, and The MARCS Institute for Brain, Behaviour and Development, Western Sydney University, Sydney, Australia*

[9]*Department of Sport Sciences, University of Beira Interior, Covilhã, Portugal*

***Corresponding Author:** Andrew Sortwell, E-mail: sortwellandrew@gmail.com

ARTICLE INFO

Article history
Received: August 11, 2022
Accepted: October 01, 2022
Published: October 31, 2022
Volume: 10 Issue: 4

Conflicts of interest: None
Funding: None

ABSTRACT

Background: The development of proficiency in motor performance skills (MPS) builds the foundation for the complex movement skills required to participate in a range of sports and physical activities throughout the lifespan. **Objective:** To assess the efficacy of different intervention approaches on developing MPS proficiency in children with autism spectrum disorder (ASD) and examine the intervention factors that influence change. **Method:** Searches were completed in three databases (PubMed/MEDLINE, Scopus, Web of Science) up to March 2022. Only randomised controlled trials (RCTs) or controlled trials (CTs), that evaluated the effectiveness of interventions on overall MPS proficiency or specific MPS such as balance, running speed and agility, bilateral coordination, jumping, ball skills and push-ups in children (4–13 years old) were included. The DerSimonian and Laird random-effects model was used to compute the meta-analyses. The effect sizes were reported as Hedges' *g*. Using a random-effects model, potential sources of heterogeneity were identified, including subgroup analyses (type of intervention), and single training factor analysis (total number of weeks, session frequency, total intervention time, total number of training sessions). In addition, a multivariate meta-regression calculation was performed for balance. The GRADE framework was applied to assess certainty of evidence. **Results**: Seventeen interventions (13 RCTs and 4 CTs) revealed significant differences among groups favouring the intervention group with moderate to very large effects. Significant ($p < 0.05$) small-to-large effects of interventions were evident on overall motor performance skills (ES = 2.43), ball skills (ES = 2.95), jumping (ES = 1.89), bilateral coordination (ES = 2.21), push-ups (ES = 1.92), balance (ES = 1.56), running speed and agility (ES = 1.31). Multivariate meta-regression for balance revealed that total sessions, total intervention time and session frequency predicted ($p = 0.009$, $p<0.001$, $p = 0.036$, respectively) the effects of interventions on change in balance performance. **Conclusion:** Structured interventions that explicitly teach traditional FMS or promote the development and learning of movement skills specifically associated with a type of physical activity or sport, effectively improve MPS in children with ASD. Education settings should implement 'planned' movement experiences or interventions as a strategy to promote MPS proficiency in children with ASD.

Key words: Education, Exercise, Intervention, Learning, Physical Education, Physical Literacy

Published by Australian International Academic Centre PTY.LTD.

http://dx.doi.org/10.7575/aiac.ijkss.v.10n.4p.34

INTRODUCTION

Childhood is a critical period for cognitive, psychological, physical, and social development (Poitras et al., 2016) and for the promotion of healthy behaviour patterns that continue into adolescence and adulthood (Ekman et al., 2022). According to a growing body of evidence, frequent engagement in physical activity during childhood is critical for optimal growth and development, resulting in both short and long-term physical and psychological well-being benefits (García-Hermoso et al., 2019; Janssen & LeBlanc, 2010). Unsurprisingly, the World Health Organization (WHO) updated its physical activity guidelines in 2020, recommending that children engage in at least 60 minutes of moderate-to-vigorous physical activity (MVPA) per day, as well as vigorously intense aerobic activities, and muscle and bone strengthening exercises at least three times per week (Chaput et al., 2020). Regular MVPA is positively associated with favourable cardiometabolic risk profiles, body composition, academic success, and health-related quality of life in children (Tremblay et al., 2016). Therefore, there is an urgent need to seek strategies and methods to enable more activity in children, especially those at greater risk of being physically inactive (Mitchell, 2019).

Children with disabilities tend to be more sedentary in comparison to children without disabilities. Additionally, children and adolescents with disabilities that experience relatively higher sedentary time, are more likely to experience health-related problems, resulting in a public health issue (Liang et al., 2020). The benefits of physical activity are also applicable to children with autism spectrum disorder (ASD) (Lang et al., 2010). For example, when children with ASD regularly participate in physical activities and sports, it has a positive effect on cognitive, psychological, and behavioural elements, as well as social and motor functioning (Chu et al., 2020; Huang et al., 2020; Liang et al., 2020). Conversely, low physical activity participation levels in children with ASD are associated with adverse short- and long-term health consequences (i.e., high rates of overweight and obesity) (Broder-Fingert et al., 2014; Croen et al., 2015; Fortuna et al., 2016; Hill et al., 2015) and low levels of health-related fitness (Coffey et al., 2021; Pan et al., 2021; Tyler et al., 2014). Despite the known benefits, physical activity levels in children with ASD have been notably lower compared to typically developing children over the last eleven years (MacDonald et al., 2011; Rostami Haji Abadi et al., 2021). Recent results from a meta-analysis (Rostami Haji Abadi et al., 2021) involving nine studies indicated that children with ASD spent an average of 30 minutes less daily in MVPA and were four times more likely to not comply with the recommended daily MVPA compared to typically developing children. Furthermore, the meta-analyses estimated that children with ASD have lower levels of MVPA in physical education classes and spend 8-12 percent less time in MVPA during PE and recess (Rostami Haji Abadi et al., 2021). The lower level of MVPA may be attributed to inadequate motor performance skills (MPS) proficiency and poor motor coordination often associated with ASD (Bishop & Pangelinan, 2018; Green et al., 2009).

Motor performance skills are essential for children and adolescents to develop specialised movement skills and sequences required for participating in many organised and non-organised sports and physical activities (Sortwell et al., 2022). Motor performance skills are classified into the following categories; (1) space-covering movements (i.e., rolling, crawling, walking, running, changing direction and dodging, (2) surmounting obstacles (i.e., jumping, landing, climbing, skipping, hopping, and leaping, (3) object manipulation (i.e., throwing, catching, shooting, targeting, tossing, dribbling), (4) overcoming resistance (i.e., pushing, pulling, holding, carrying) (Sortwell et al., 2022). The development of proficiency in MPS increases the individual's ability to adapt to situations with increasing demands with respect to form, speed, accuracy and complexity of the skill performed. In children with ASD, there is renewed interest in developing MPS due to growing evidence suggesting that impairments in movement skills precede, and even exacerbate, social-communicative symptoms in ASD (Elliott et al., 2021; Gandotra et al., 2020). Moreover, MPS are optimally developed in childhood and refined into context-specific physical activities or sport-specific skills (i.e., lay-up in basketball), as childhood is a critical period of learning (Barnett et al., 2016; Solum et al., 2020). For instance, during the early years in primary school physical education classes, underarm and overarm throwing is taught and learnt, and then the skill is refined in middle and high school for pitching in baseball or serving in tennis. If children with ASD acquire MPS proficiency, this can improve access and opportunities to participate in various physical activities, games and sports throughout their daily lives (Bremer & Cairney, 2016; Elliott et al., 2021; Ketcheson et al., 2017). There is growing evidence to suggest that there is a reciprocal relationship between MPS proficiency and participation in physical activity (Holfelder & Schott, 2014; Xin et al., 2020) and the associated health benefits (i.e., physical, psychological, and social) (Barnett et al., 2016). In children with ASD, MPS proficiency may be a prelude to greater participation in physical activity and opportunities to improve health and also social skills (Lopez-Diaz et al., 2021).

Compared to typically developing children, children with ASD are more likely to have significant impairments in object control (i.e., catching, throwing, and kicking) and locomotor MPS competencies (Berkeley et al., 2001; Gandotra et al., 2020; Pan et al., 2009). The importance of these two MPS (i.e., object control, locomotor skills) competencies for participation in physical activity has been examined in longitudinal studies involving predominantly typically developing children. Duncan and colleagues (Duncan et al., 2021) followed a sample of 177 preschool children over one-year and found that locomotor and object control skill performance were strong predictors of children's level of sedentary activity. In another study, Vlahov and colleagues (Vlahov et al., 2014) examined the relationship between MPS in 140 preschool children and health-related physical fitness with a follow-up 11 years later. The results indicated that both object control and locomotor skill proficiency in preschool significantly predicted all aspects of fitness in adolescence.

These indicators are relevant considering that physical fitness is a fundamental characteristic to participate in sports activities and successfully perform required skills (e.g., throwing, jumping, kicking, sprinting) (Larsen et al., 2017). Lastly, Barnett et al. (2009), in a six-year longitudinal study of 276 children from age ten to sixteen, found that object control skills were significantly and positively associated with participation in MVPA. This is especially troubling in children with ASD, as a recent systematic review of the fundamental movement skills showed that the majority of children with ASD demonstrated significant impairments, and cognitive abilities alone were unable to explain motor skill issues (Gandotra et al., 2020; Hilton et al., 2007; Whyatt & Craig, 2012). Higher rates of MPS impairments in children with ASD may mean they are less likely to participate in physical activity and sports programs (Cuesta-Gómez et al., 2022). Therefore, if children with ASD acquire MPS proficiency, it may pave the way for increased opportunities to participate in sports, games, and other physical activities (Gandotra et al., 2020).

Research studies to date examining the effect of movement-based interventions on MPS in children with ASD have generally included small sample sizes, even as low as two. This has raised some controversy relating to the meaningfulness of the findings, resulting from the preclusion of robust statistical analysis. However, this controversy can be partially resolved with a meta-analysis based on a strict criterion regarding the quality of studies to be included. Although there have been two previous systematic reviews and meta-analyses attempting to describe the effect of MPS interventions on youth with ASD (Case & Yun, 2019; Huang et al., 2020), the reviews only provided an overall effect for motor skills or gross motor outcomes rather than the effect on specific skills. Furthermore, Case and Yun (2019) included studies that did not include a control group which is necessary to serve as a baseline for determining the effectiveness of an intervention, and Huang et al. (2020) included studies with adolescents. Moreover, the role of potential moderators (e.g., session frequency, total period of intervention duration, number of sessions) on the MPS response to interventions in children with ASD has been somewhat neglected in the literature. Additionally, with the advancement of meta-analytical techniques, new data analysis procedures are more commonly used, including multivariate meta-regressions, allowing additional insights into the role of potential moderators and their related covariates. Therefore, there is a need to have a deeper understanding of the effectiveness of MPS interventions on children with ASD. Thus, there were three main objectives of this systematic review and meta-analysis: (1) to evaluate the effect of interventions on motor performance skill proficiency; (2) to determine if the type of intervention, traditional FMS-themed instruction or physical activity movement-themed interventions were more effective in improving specific MPS; and (3) to identify intervention characteristics (i.e., session frequency, total sessions, total time, total weeks) that may moderate the effect on MPS outcomes.

METHOD

Protocol and Registration

This study was conducted following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009). The study is registered with Open Science Framework (OSF): https://osf.io/hv625/.

Literature Sources and Search

The literature searching was performed using electronic searches of PubMed (comprising MEDLINE), Web of Science, and Scopus, from inception through to March 2022, combined with manual searches of the existing literature. The search strategy was conducted using the Boolean operators AND as well as OR with the following keywords; "motor", "performance", "skill", "fitness", "fundamental", "movement", "ability", "autism", "spectrum", "gross", "fine", "locomotor", "velocity", "balance", "Asperger", "syndrome", "skills", "fundamental", "movement", "abilities", "coordination", "spectrum", "non-locomotor", "children", "school", "primary", "intervention", "training". Examples of combinations included: "motor ability" AND "autism"; ("fundamental movement skills" OR "balance" OR "fitness") AND "autism". Also, the reference lists of the included studies were checked to find potential studies not identified by the search that could also be used in this review. Two of the authors (AS, KT) completed the search, removed duplicates, and screened the papers.

Eligibility Criteria and Study Selection

For the initial development of the eligibility criteria, the PICOS (participants, intervention, comparators, outcomes, and study design) approach was used to rate studies for eligibility (Methley et al., 2014) (Table 1). Selection criteria using the PICOS approach were then further refined. Research studies needed to comply with the following criteria to be included: (1) the target group were children with ASD; (2) the research type was experimental; (3) randomised (RCTs) and/or controlled trials (CTs) in which the comparison or control group received no structured or deliberate change to their regular physical activities and received no other type of intervention (e.g. academic tuition); (4) the experimental group had an obvious physical movement intervention; (5) the intervention was supervised; (6) at least one motor performance skill assessed pre and post-study; (7) to be available in full text and in English. The criteria for study exclusion were; (1) the intervention was not clearly defined; (2) participants were outside the age range of 4-13 years old; (3) participants included children without ASD; (4) inadequate and/or incomplete information about the assessment used to measure outcomes; (5) lack of baseline and/or follow-up data. Two authors (AS and KT) independently screened the titles, and abstracts, followed by full-text versions of retrieved studies being assessed. During the review process, potential discrepancies between the same two authors (AS and KT) regarding inclusion and exclusion criteria were resolved through consensus with a third author (PF).

Table 1. Selection criteria used in the meta-analysis

Category	Inclusion criteria	Exclusion criteria
Population	Participants ≤ 13 years of age (i.e., group mean value) and > 3 years of age, diagnosed with ASD, with no restrictions on their fitness level, sport practiced.	Participants without ASD.
Intervention	A physical education or training/exercise program of ≥ 2 weeks (≥4 total training sessions) aimed to improve motor performance skills and changes in movement skills measured pre and post.	Intervention lasted less than two weeks. Interventions developed for rehabilitation purposes. Not involving a type of physical education or training/ exercise intervention.
Comparator	Studies comparing a control group with a test group. The test group had an intervention, while the control group did not.	Absence of a control group. The control group had an intervention.
Outcome	At least one measure of motor performance skills (overall MPS, balance, bilateral coordination, jumping, push-ups, speed and agility) was assessed before and after the intervention.	Lack of baseline and/or follow-up data.
Study design	Controlled with intervention and comparison group.	

ASD = autism spectrum disorder; MPS = motor performance skills

Data Collection Process

The data collection process was carried out independently by two researchers (KT and AS). Any discrepancies between them were resolved through discussion with a third reviewer (PF). For each of the included studies, the following data were extracted: (1) author's last name and year of publication; (2) participant characteristics (sample size, gender and age); (4) characteristics of the intervention (types, frequency, duration); (5) outcomes measured; (6) pre and post-intervention mean values with corresponding standard deviations. Data extraction was completed using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). When there was insufficient information, the respective corresponding author and a co-author of the paper were contacted via email. If no response was received after two attempts over a four-week period, the study was excluded from the analysis unless the following methods could be carried out; (1) if graphical plots were present, data were extracted by using WebPlotDigitizer (version 4.5, https://apps.automeris.io/wpd/) (Drevon et al., 2017); (2) if the outcome measures were expressed as median (25–75 quartile), they were transformed into the standard form of mean, according to the Cochrane book or method (Hozo et al., 2005).

Methodological Quality of Individual Studies

The risk of bias in individual studies were evaluated using the Physiotherapy Evidence Database (PEDro) criteria (Maher et al., 2003). PEDro is a valid and reliable eleven-item scale designed for measuring the quality of CTs and RCTs (de Morton, 2009; Yamato et al., 2017). Moreover, the PEDro scale is used frequently in the literature related to children with ASD (Amonkar et al., 2021; Case-Smith et al., 2015) and the development of MPS in children (Behringer et al., 2011; Lucas et al., 2016). Thus, it helps to compare meta-analyses. The evaluation using PEDro was independently completed by two authors (PF and KS) to assess the methodological quality of RCTs and CTs included within this systematic review and meta-analyses. The PEDro item scale was scored on a dichotomous scale (No = 0, Yes = 1), of which 10 of the 11 items were scored to obtain a study score out of a maximum possible score of 10 (the first item on the PEDro is not included in the total score) (Moseley et al., 2002). Briefly, studies with ≤ 3 points were considered poor quality, 4–5 points as moderate quality, and 6–10 points as high quality (Cashin & McAuley, 2020).

Summary Measures, Synthesis of Results and Risk of Bias Assessment

All statistical analyses were performed using SPSS Software for Windows (Version 28, IBM Corporation Amrok, New York). Meta-analytical comparisons were only conducted if ≥ 3 studies were available for the outcome (Skrede et al., 2019) and were completed for continuous data using the change in the mean and standard deviation of outcome measures. Hedges' *g* effect size was calculated and pooled using the DerSimonian and Laird inverse random-effects model for meta-analyses. Effect size values are presented with 95% confidence intervals (95% CIs). The calculated effect size was classified as: <0.2 trivial, 0.2–0.6 small, >0.6–1.2 moderate, >1.2–2.0 large, >2.0–4.0 very large, > 4.0 extremely large (Hopkins et al., 2009). In cases where there was more than one intervention group in a study using different strategies, the data were analysed as independent studies, and the number of participants in the control group was proportionately divided to facilitate comparisons across all participants (Higgins et.al, 2022).

The level of heterogeneity across the studies was assessed using the I^2 statistic, with values of <25%, 25–74%, and ≥ 75% considered to represent low, moderate, and high levels, respectively (Higgins & Thompson, 2002). Sensitivity analysis was conducted to determine the source of heterogeneity when high levels were detected. When high heterogeneity is detected, references are removed one at a time to test whether a study or a number of studies significantly impacted the overall effect on the outcome. Egger's regression test was also performed to detect bias across studies, with $p < 0.05$ implying bias (Egger et al., 1997). To adjust for publication bias, a sensitivity analysis was conducted using the trim and fill method (Duval & Tweedie, 2000), with L0 as the default estimator for the number of missing studies (Shi & Lin, 2019).

Additional Analysis

To identify the potential parameters that may contribute to larger effects and based on the context of the instruction in the studies, interventions were categorised as fundamental movement skills or physical activity movement-themed interventions. Fundamental movement skill interventions consisted of participants learning the movement patterns required to perform balancing, locomotor and object control/manipulation skills via direct instruction, typically assessed using the Test of Gross Motor Development Second Edition (TGMD-2) (Allen et al., 2017) or Bruininks-Oseretsky Test of Motor Proficiency Second Edition (BOT-2) (Bruininks-Oseretsky, 1978). Both tests are norm-referenced measures, TGMD-2 assesses common gross motor skills, and the BOT-2 assesses motor skills that develop early in life. Physical activity movement-themed interventions required participants to engage in themed activities requiring the development and application of gross motor skills related to aquatics, martial arts, tennis, basketball, or fitness (trampolining). Whenever possible, moderator analyses were conducted when ≥ 3 studies per moderator were available. A subgroup analysis was conducted according to the intervention type- fundamental movement skill or physical activity movement-themed intervention. Single intervention factor analyses were performed when possible, according to the intervention parameters, (i) number of weeks, (ii) number of sessions, (iii) weekly frequency, and (iv) total intervention time. For the single intervention factor analysis, a global median value was used for the application of the median split technique. In addition, a multivariate random-effects meta-regression was used to determine if any of the intervention parameters (e.g., type; the number of weeks; the total number of sessions; total time) predicted the effect of change in motor performance skill outcome when there were at least ten studies (Higgins et al., 2022).

A Grading of Recommendations Assessment, Development, and Evaluation (GRADE) framework was used to assess the certainty of the evidence across studies at an outcome level (Guyatt et al., 2011). When three or more studies reporting on the same outcome were grouped, the risk of bias, precision, consistency, and directness was assessed. To determine the imprecision rating, one level of downgrading occurred whenever <300 participants were available for comparison and/or if there was no clear direction of the effects. Based on these assessments, the certainty of the evidence was upgraded or downgraded to provide an overall rating for the certainty of the evidence: very low, low, moderate, and high (Guyatt et al., 2011). For non-randomised controlled trials, the start rating was always low; however, as per GRADE guidance, it could be upgraded.

RESULTS

Study Selection

The identification of papers using an electronic search strategy retrieved 16,416 (see PRISMA flow Figure 1). Following the removal of duplicates and screening of titles and abstracts, 190 papers were assessed for eligibility. After a full read and according to inclusion-exclusion criteria, 14

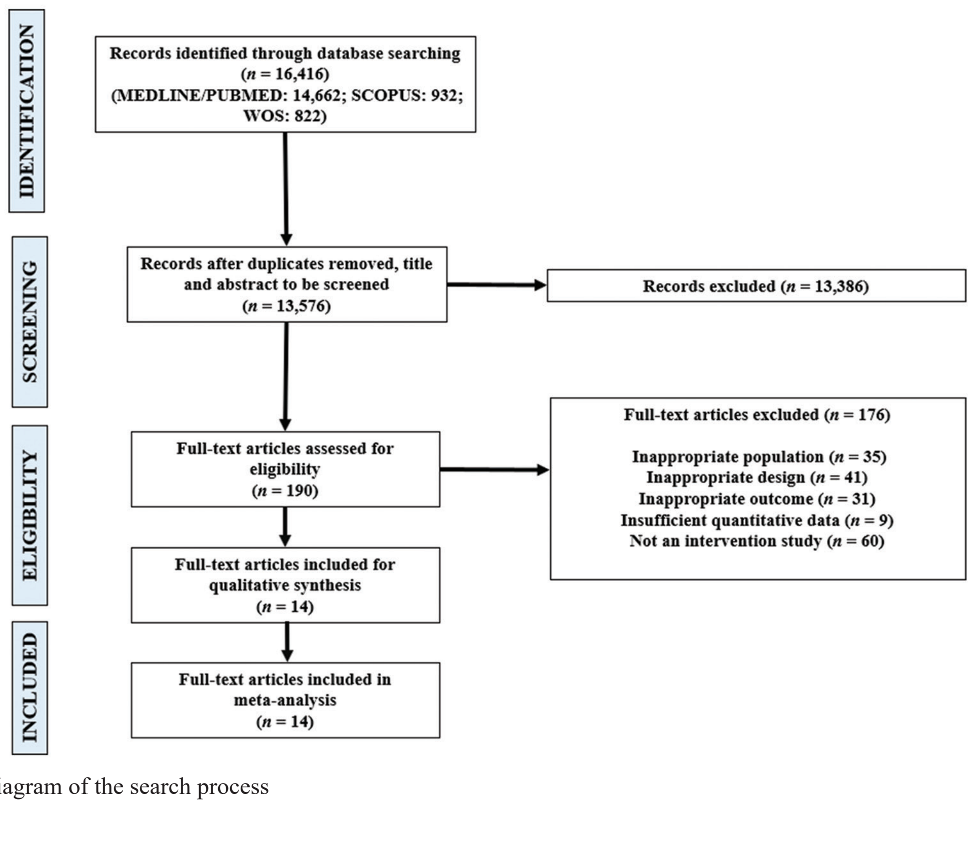

Figure 1. Flow diagram of the search process

papers were included in the qualitative and quantitative analysis in this paper.

Study Characteristics

The characteristics of each study are summarised in Table 2. Among the 14 studies, there were 17 different interventions included in the meta-analysis because three of the 14 included studies involved more than one intervention (Ansari et al., 2021; Hassani et al., 2022; Rafiei et al., 2021). The meta-analysis included a total of 365 children ranging in mean age from four (Felzer-Kim & Hauck, 2020) to 10 years (Zamani Jam et al., 2018). Most studies included boys and girls (n = 11), except for three (Ansari et al., 2021; Najafabadi et al., 2018; Pan et al., 2017). The studies in this analysis were published between 2015 and 2022. The participant sample group sizes ranged from six (Felzer-Kim & Hauck, 2020; Kim et al., 2016; Lourenco et al., 2015) to thirty (Dong et al., 2021).

The 17 analysed interventions focused on developing gross motor skills (e.g., jumping, running, balancing) through engagement in either physical activity movement-themed activities (n = 11) or learning the motor pattern of specific fundamental movement skills (n = 6). The control groups that participated in the studies continued their regular daily activities without any structured adjustment or change. The duration of the interventions ranged from six weeks (Sarabzadeh et al., 2019) to 32 weeks (Lourenco et al., 2016). Of the 17 interventions, 11 included fitness training and/or fitness exercises as a minor component. Of the FMS focused interventions, 33.3% (n = 2) included fitness exercises, while 81.8% (n = 9) of the physical activity movement-themed interventions included fitness exercises. Seven (58%) of the themed physical activity movement-themed activities used a specific sport, and five (41.67 %) used fitness, games or recreational activities (i.e., Tai Chi) as the central theme.

The outcome measures reported in the papers analysed include; overall motor performance skills, balance, running speed and agility, bilateral coordination, jumping, ball skills and push-ups. Outcomes measures assessments were based on the TGMD-2, BOT-2, Movement Assessment Battery for Children, as well as other standardised tests.

Risk of Bias Within Studies

Using the PEDro checklist, the average total bias score was 6.29, ranging from four to eight, and the median score was six. Three studies scored four to five points and were classified as being of moderate quality, while ten were in the range of six-to-eight-points and therefore considered of high methodological quality (Table 3). A large number of the studies failed to conceal allocation, blind subjects and therapists and blind assessors. This pronounced methodological problem among the interventions occurs because it is difficult to blind the subjects and the therapists delivering the intervention to the treatment.

Summary of Evidence

Summary results and forest plots of the meta-analyses for overall MPS, balance, running speed and agility, ball skills, bilateral coordination, jumping, and push-up are described below. In the forest plots, the black squares represent individual studies, the size of the squares represents relative weights, and the red diamonds represent the overall point estimate and 95% confidence intervals from all individual studies included in each meta-analysis.

Seven studies provided data for overall MPS proficiency, involving eight experimental and seven control groups (pooled n = 178). There was a significant effect of intervention on overall MPS proficiency (g = 2.43; 95% CI = 1.55 to 3.57; p = 0.001; I^2 = 79%; Egger's test p = 0.41; Figure 2). After applying the trim and fill method, the adjusted values remained as the observed values. The relative weight of each study in the analysis ranged from 3.31% to 16.94%. Sensitivity analysis was conducted to identify the source of the high heterogeneity. Heterogeneity dropped to zero after deleting the results of two interventions (Hassani et al., 2022; Ketcheson et al., 2017). An intervention's confidence interval did not overlap with the confidence interval of the pooled effect and therefore can be considered an outlier (Viechtbauer & Cheung, 2010). If this intervention were to be excluded within the scope of a separate robustness analysis, a large and significant treatment effect would still be found (g = 2.12; 95% CI = 1.36 to 2.89; p = <0.001; I^2 = 66.0%; Egger's test p = 0.77).

Eleven studies provided data for balance, and there were 13 experimental and 11 control groups (pooled n = 310). There was a significant effect of intervention on balance (g = 1.56; 95% CI = 0.95 to 2.17; p = <0.001; I^2 = 74.2%; Egger's test p = 0.01; Figure 3). After applying the trim and fill method, the adjusted values remained as the observed values. The relative weight of each study in the analysis ranged from 4.55% to 9.35%. Two intervention's confidence intervals did not overlap with the confidence interval of the

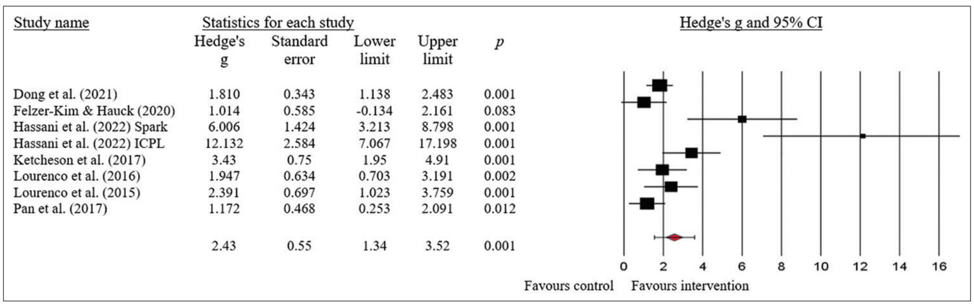

Figure 2. Forest plot showing the effect size (Hedges' g) of interventions on overall motor performance skill proficiency

Table 2. Summary of included studies

Study	Gender (*n*)	Number and mean age of groups	Intervention type and content	Total weeks	Weekly frequency	Total session	Time of sessions (min)	Total time (min)	MPS assessed	PEDro rating
Ansari et al. (2021) Aquatics	Boys (20)	IG *n* = 10; 10.60 ± 2.50 CG *n* = 10; 10.80 ± 2.44	(PAMT) Aquatic training involving swimming skills, fitness and play.	10	2	20	60	1200	Balance	6
Ansari et al. (2021) Kata	Boys (20)	IG *n* = 10; 10.80 ± 2.14 CG *n* = 10 10.80 ± 2.44	(PAMT) Kata training consisting of blocking, punching, sticking, and kicking exercises.	10	2	20	60	1200	Balance	6
Cai et al. (2020)	Boys (26); Girls (4)	IG *n* =15; 5.03 ± 0.64 CG *n* =15; 4.56 ± 0.84	(PAMT) Mini-basketball training program with a focus on fitness and basketball skills	12	5	60	40	2440	Balance, speed and agility, jump	6
Dong et al. (2021)	Boys (42); Girls (10)	IG *n* = 22; 8.04 ± 1.53 CG *n* = 30; 7.48 ± 1.36	(FMS) Fundamental movement skill instruction.	9	3	27	80	2160	Overall MPS, ball skills	6
Felzer-Kim & Hauck (2020)	Boys (10); Girls (4)	IG *n* = 8; 4.48 ± .59 CG *n* = 6; 4.49 ± .58	(FMS) Teaching and learning of 13 fundamental movement skills	10	4	40	15	600	Overall MPS	8
Hassani et al. (2022) Spark	Boys (12); Girls (7)	IG *n* = 10; 9.10 ± 0.87 CG *n* = 9; 8.70 ± 0.70	(FMS) Motor training program, which deals with teaching locomotor, balance and manipulative fundamental movement skills	8	2	16	60	960	Overall MPS, balance, speed and agility, bilateral coordination push-up	6
Hassani et al. (2022) ICPL	Boys (14); Girls (6)	IG *n* = 11 8.55 ± 0.68 CG *n* = 9 8.70 ± 0.70	(FMS) Teaching locomotor, balance, kicking, throwing skills with visual aids with a focus on fun	8	2	16	60	960	Overall MPS, balance, speed and agility, bilateral coordination, push-up	6
Ketcheson et al. (2017)	Boys (15); Girls (5)	IG *n* = 11 4.87 ± 0.61 CG *n* = 9 5.05 ± 0.62	(FMS) Fundamental movement skill instruction	8	5	40	240	9600	Overall MPS	5
Kim et al. (2016)	Boys (13); Girls (1)	IG *n* = 8; 10.25 ± 2.38 CG *n* = 6; 10.00 ± 2.83	(PAMT) Taekwondo training involving stances, blocks, punches and kicks	8	2	16	50	800	Balance	4

(*Contd...*)

Table 2. (*Continued*)

Study	Gender (*n*)	Number and mean age of groups	Intervention type and content	Total weeks	Weekly frequency	Total session	Time of sessions (min)	Total time (min)	MPS assessed	PEDro rating
Lourenco et al. (2016)	Boys (13); Girls (3)	IG *n* = 8; 5:43 ± 1:53 CG *n* = 8; 7.60 ± 1.60	(PAMT) Trampoline training and exercises involving running, jumping, games	32	1	32	45	1440	Overall MPS, balance, ball skills, bilateral coordination, jump, push-up	5
Lourenco et al. (2015)	Boys (12); Girls (5)	IG *n* = 6; 5.13 ± 1.55 CG *n* = 11; 8 ± 2.190	(PAMT) Trampoline training and exercises involving running, jumping, games	20	1	20	45	900	Overall MPS, balance, bilateral coordination, jump, push-up	6
Najafabadi et al. (2018)	Boys (26)	IG *n* = 12; 7.08 ± 2.06 CG *n* = 14; 5.13 ± 2.23	(PAMT) The Spark program. Health / skill fitness activities related to stability and displacement movements	12	3	36	40	1440	Balance	8
Pan et al. (2017)	Boys (22)	IG *n* = 11; 9.68 ± 1.61 CG *n* = 11; 8.49 ± 1.76	(PAMT) Table tennis involving practicing technical skills specific to table tennis associated body movement skills.	12	2	24	70	1680	Overall MPS	7
(Rafiei et al. (2021) Spark	Boys (28); Girls (2)	IG *n* = 20; 7.95 ± 1.60 CG *n* =20; 8.45 ± 1.43	(FMS) Motor training program, which deals with teaching manipulative skills and involved balance.	8	2	16	35	560	Balance, ball skills	7
Rafiei et al. (2021) Kinect	Boys (28); Girls (2)	IG *n* = 20; 8.15 ± 1.50 CG *n* =14; 8.45 ± 1.43	(PAMT) Kinect required children to participate in tennis videogame activities.	8	2	16	35	560	Balance, ball skills	7
Sarabzadeh et al. (2019)	Boys (14); Girls (4)	IG *n* = 9; 8.88 ± 1.76 CG n=9; 8.22 ± 1.92	(PAMT) Tai Chi Chuan involving balance, physical fitness, body awareness, neural control, proprioceptive coordination exercises.	6	3	18	60	1080	Balance, ball skills	7

(*Contd...*)

Table 2. (*Continued*)

Study	Gender (*n*)	Number and mean age of groups	Intervention type and content	Total weeks	Weekly frequency	Total session	Time of sessions (min)	Total time (min)	MPS assessed	PEDro rating
Zamani Jam et al. (2018)	Boys (17); Girls (13)	IG n = 15; 10.20 CG n = 15; 10.12	(PAMT) Preliminary and basic gymnastic exercises.	16	3	48	45	2160	Balance, speed and agility, bilateral coordination, push-up	7

min = minutes; IG = intervention group; CG = control group; (FMS) = fundamental motor skills; (PAMT) = physical activity movement theme; MPS = motor performance skills

Table 3. The methodological quality of the included studies using the PEDro rating scale

Study	1	2	3	4	5	6	7	8	9	10	11	*Score	Study quality
Ansari et al. (2021)	1	1	0	1	0	0	0	1	1	1	1	6	High
Cai et al. (2020)	1	1	0	1	0	0	0	1	1	1	1	6	High
Dong et al. (2021)	1	1	0	1	0	0	0	1	1	1	1	6	High
Felzer-Kim & Hauck (2020)	1	1	1	1	1	0	0	1	1	1	1	8	High
Hassani et al. (2022)	1	0	0	1	0	1	0	1	1	1	1	6	High
Ketcheson et al. (2017)	1	0	0	1	0	0	0	1	1	1	1	5	Moderate
Kim et al. (2016)	1	0	0	0	0	0	0	1	1	1	1	4	Moderate
Lourenco et al. (2015)	1	1	0	1	0	0	0	1	1	1	1	6	High
Lourenco et al. (2016)	1	0	0	1	0	0	0	1	1	1	1	5	Moderate
Najafabadi et al. (2018)	1	1	0	1	1	0	1	1	1	1	1	8	High
Pan et al. (2017)	1	1	0	1	1	0	0	1	1	1	1	7	High
Rafiei et al. (2021)	1	1	1	1	0	0	0	1	1	1	1	7	High
Sarabzadeh et al. (2019)	1	1	1	1	0	0	0	1	1	1	1	7	High
Zamani Jam et al., (2018)	1	1	0	1	1	0	0	1	1	1	1	7	High

*From a possible maximal score of 10. A detailed explanation for each PEDro scale item can be accessed at https://www.pedro.org.au/english/downloads/pedro-scale

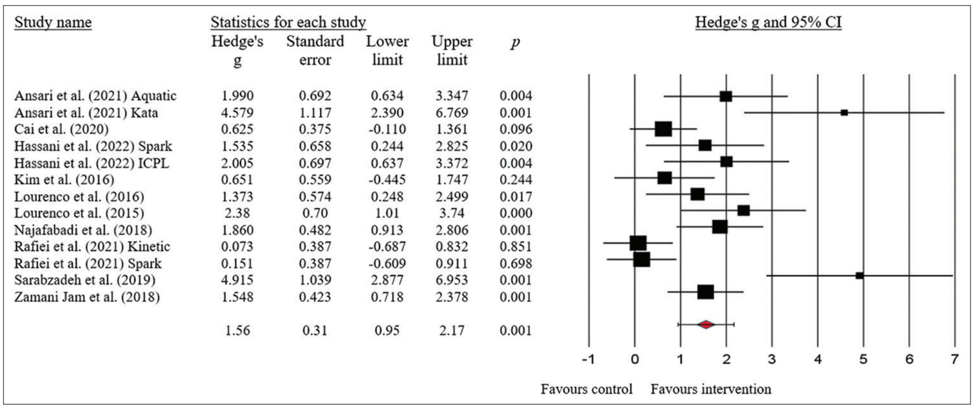

Figure 3. Forest plot showing the effect size (Hedges' g) of interventions on balance

pooled effect. If these two interventions were considered as outliers and excluded within the scope of a separate robustness analysis, a moderate and significant treatment effect would still be found (g = 1.18; 95% CI = 0.69 to 1.66; p = <0.001; I^2 = 61.4%; Egger's test p = 0.13).

Four studies provided data for running speed and agility, five experimental and four control groups (pooled n = 106). There was a significant effect of intervention on running speed and agility (g = 1.31; 95% CI = 0.63 to 2.30; p = 0.001; I^2 = 67.5%; Egger's test p = 0.25; Figure 4). After applying the trim and fill method, two studies were imputed, and the adjusted values changed (g = 1.03; 95% CI = 0.26 to 1.81). The relative weight of each study in the analysis ranged from 15.19% to 25.39%.

Seven studies provided data for ball skills, nine experimental and seven control groups (pooled *n* = 250). There was a significant effect of intervention on ball skills (*g* = 2.95; 95% CI = 1.35 to 4.54; *p* = 0.001; I^2 = 94%; Egger's test *p* = 0.14; Figure 5). After applying the trim and fill method, two studies were imputed, and the adjusted values changed (*g* = 1.87; 95% CI = 0.30 to 3.43). The relative weight of each study in the analysis ranged from 6.46% to 12.65%. Heterogeneity reduced to 22% after deleting the results of five interventions (Dong et al., 2021; Hassani et al., 2022; Sarabzadeh et al., 2019; Zamani Jam et al., 2018). Three intervention's confidence intervals did not overlap with the confidence interval of the pooled effect. Additionally, the meta-analytical procedure was performed without these interventions, leading to a moderate and significant treatment effect (*g* = 1.03; 95% CI = -0.03 to 2.10; *p* = 0.05; I^2 = 85.4%; Egger's test *p* = 0.12.

Four studies provided data for bilateral coordination, five experimental and four control groups (pooled *n* = 93). There was a significant effect of intervention on bilateral coordination (*g* = 2.21; 95% CI = 0.75 to 3.68; *p* = 0.01; I^2 = 84.2%; Egger's test *p* = 0.14; Figure 6). After applying the trim and fill method, one study was imputed, and the adjusted values changed (*g* = 1.51; 95% CI = -0.14 to 3.17). The relative weight of each study in the analysis ranged from 10.58% to 24.87%. Heterogeneity was reduced to zero after deleting the results of one study (Hassani et al., 2022).

Three studies provided data for jumping, involving three experimental and three control groups (pooled *n* = 63). There was a significant effect of intervention on jumping (*g* = 1.89; 95% CI = 0.96 to 2.83; *p* = 0.01; I^2 = 50.6%; Egger's test *p* = 0.92; Figure 7). After applying the trim and fill method, the adjusted values remained as the observed values. The relative weight of each study in the analysis ranged from 22.88% to 42.10%.

Four studies provided data for push-ups, involving five experimental and four control groups (pooled *n* = 93). There was a significant effect of intervention on push-ups (*g* = 1.92; 95% CI = 0.41 to 3.44; *p* = 0.013; I^2 = 86.5%; Egger's test *p* = 0.04; Figure 8). After applying the trim and fill method, the adjusted values remained as the observed values. The relative weight of each study in the analysis ranged from 14.1% to 23.56%. Sensitivity analysis was conducted to identify the source for the high heterogeneity. Heterogeneity was reduced to 68% after deleting the results of one study (Hassani et al., 2022).

Additional Analyses

Moderator analyses were considered for ball skills, overall MPS and balance given that ≥ 3 studies per moderator were available. Subgroup analysis revealed that FMS themed interventions alone favoured larger significant improvements in ball skills (*g* = 3.64; 95% CI = 0.86 to 6.41; I^2 = 95.8%) and overall MPS (*g* = 3.64; 95% CI = 1.77 to 5.50; I^2 = 86.6%).

Study name	Hedge's g	Standard error	Lower limit	Upper limit	*p*
Cai et al. (2020)	1.308	0.407	0.509	2.107	0.001
Hassani et al. (2022) Spark	1.807	0.690	0.453	3.160	0.009
Hassani et al. (2022) ICPL	2.505	0.786	0.962	4.047	0.001
Lourenco et al. (2016)	2.17	0.66	0.87	3.47	0.001
Zamani Jam et al. (2018)	0.259	0.366	-0.460	0.979	0.479
	1.31	0.47	0.39	2.23	0.01

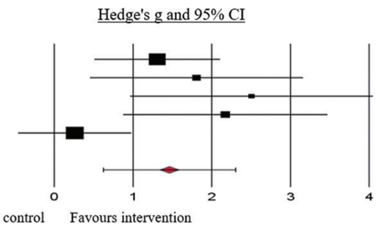

Figure 4. Forest plot showing the effect size (Hedges' g) of interventions on running speed and agility

Study name	Hedge's g	Standard error	Lower limit	Upper limit	*p*
Dong et al. (2021)	6.049	0.692	4.692	7.405	0.00
Hassani et al. (2022) Spark	4.66	1.16	2.38	6.93	0.00
Hassani et al. (2022) ICPL	10.03	2.16	5.80	14.26	0.00
Lourenco et al. (2016)	0.522	0.517	-0.493	1.536	0.314
Lourenco et al. (2015)	0.27	0.5	-0.72	1.26	0.19
Rafiei et al. (2021) Kinetic	-0.518	0.393	-1.290	0.254	0.189
Rafiei et al. (2021) Spark	0.407	0.391	-0.360	1.174	0.298
Sarabzadeh et al. (2019)	7.838	1.551	4.797	10.878	0.001
Zamani Jam et al. (2018)	2.4	0.49	1.43	3.37	0.00
	2.95	0.81	1.35	4.54	0.01

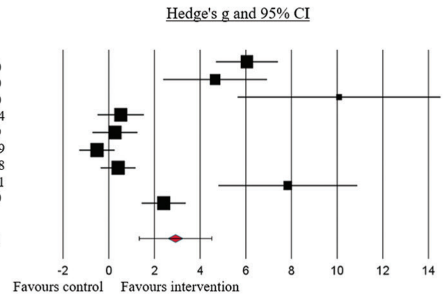

Figure 5. Forest plot showing the effect size (Hedges' g) of interventions on ball skills

Study name	Hedge's g	Standard error	Lower limit	Upper limit	*p*
Hassani et al. (2022) Spark	4.251	1.085	2.124	6.378	<0.001
Hassani et al. (2022) ICPL	8.169	1.788	4.663	11.675	<0.001
Lourenco et al. (2016)	0.550	0.518	-0.467	1.567	0.289
Lourenco et al. (2015)	0.776	0.524	-0.252	1.804	0.139
Zamani Jam et al. (2018)	1.234	0.403	0.443	2.024	0.002
	2.21	0.75	0.75	3.68	0.000

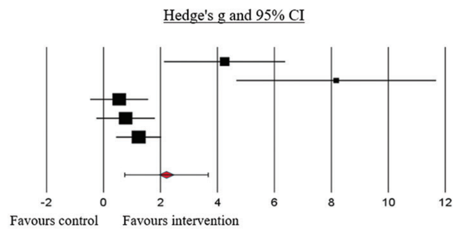

Figure 6. Forest plot showing the effect size (Hedges' g) of interventions on bilateral coordination

Whereas for balance, subgroup analysis showed that physical activity movement-themed interventions favoured significant improvements (g = 1.7; 95% CI = 0.89 to 2.53; I^2 = 79.3%). Single factor analyses for ball skills showed that greater improvements were achieved when participants performed more than two sessions per week compared to ≤ 2, engaged in less than < 22 sessions as opposed to ≥ 22. In relation to the total time and weeks (i.e., minutes and weeks) of the intervention for the development of ball skills, greater improvements were achieved when the intervention was longer than 900 minutes, and the total weeks were less than 10 weeks (see Table 4). For overall motor performance skills proficiency, greater improvements were achieved in participants engaged in ≤ 2 sessions per week, participated in ≤ 22 sessions as opposed to > 22, and the total time of engagement in the intervention over the course of the study was ≤ 960 compared to > 960 and lastly, total weeks was less than ten weeks (see Table 5). Greater improvements in balance were achieved when participants performed more than two sessions per week compared to ≤ 2, engaged in ≥ 40 sessions as opposed to < 20 or ≥ 20 < 40 sessions, and the total time of engagement in the intervention over the course of the study was > 900 and < 1440 minutes compared to ≤ 900 and ≥ 1440, total weeks was ≥10 and <16 (see Table 6).

Multivariate meta-regression analyses were able to be computed for balance (≥ 10 studies), and it included five intervention variables (type of intervention, total number of weeks, total number of sessions, total time of intervention and session frequency) (Table 7). The training variables total sessions, total time and weekly frequency were found to predict the effects of the intervention on balance (p = 0.009, p<0.001, p =.036, respectively), with I^2 = 42.1 and R^2 = 76.1.

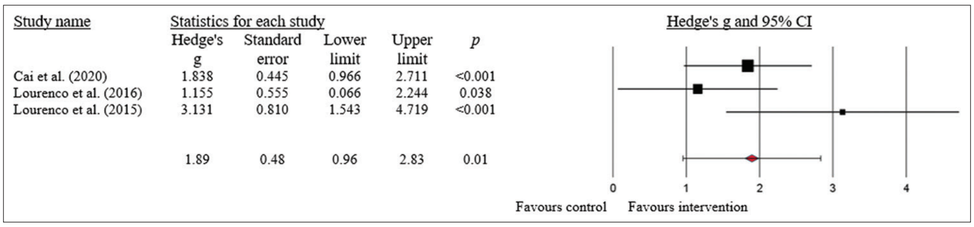

Figure 7. Forest plot showing the effect size (Hedges' g) of interventions on jumping

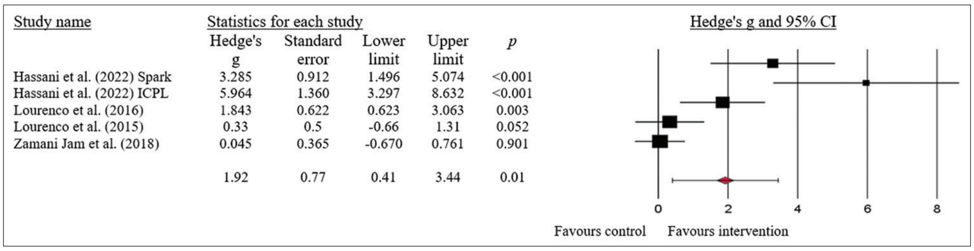

Figure 8. Forest plot showing the effect size (Hedges' g) of interventions on push-up performance

Table 4. Intervention factor moderator analysis for ball skills

Moderator	Grouping	Effect-size statistics					Heterogeneity
		N	g	SE	95% CI	p	I^2 (%)
Intervention types	FMS	5	3.64	1.41	0.86 to 6.41	0.010	95.8
	PAMT	4	2.21	0.97	0.37 to 4.11	0.022	89.7
Randomisation	Yes	6	2.45	0.97	0.54 to 4.35	0.012	95
	No	3	4.64	2.38	-0.03 to 9.31	0.051	92.1
Session frequency	≤ 2	6	1.37	0.66	0.07 to 2.67	0.040	86.6
	> 2	3	5.22	1.62	2.05 to 8.39	0.001	92.1
Total sessions	< 22	5	3.76	1.28	1.25 to 6.28	0.003	93.5
	≥22	4	2.27	1.16	0.01 to 4.54	0.050	94.5
Total time (minutes)	≤900	3	0.10	0.34	-0.56 to 0.77	0.766	46.4
	>900<1440	3	7.11	1.57	4.03 to 10.19	<0.001	65.3
	≥1440	3	2.87	1.53	-0.13 to 5.87	0.060	95.6
Total weeks	<10	5	3.76	1.28	1.25 to 6.28	0.003	93.3
	≥10	4	2.27	1.16	0.01 to 4.54	0.050	94.5

N = number of studies; g = effect size; SE = standard error; CI = confidence interval; p = level of significance; I^2 = heterogeneity; FMS = fundamental motor skills; PAMT = physical activity movement theme

Table 5. Intervention factor moderator analysis for overall motor performance skills

Moderator	Grouping	Effect-size statistics					Heterogeneity
		N	*g*	SE	95% CI	*p*	I^2 (%)
Intervention types	FMS	5	3.64	0.95	1.77 to 5.50	<0.001	86.6
	PAMT	3	1.69	0.37	0.97 to 2.41	<0.001	16.2
Randomisation	Yes	4	1.58	0.26	1.06 to 2.09	<0.001	14.2
	No	4	4.92	1.37	2.23 to 7.61	<0.001	84.9
Session frequency	≤2	5	3.50	0.97	1.59 to 5.40	<0.001	85.0
	>2	3	1.98	0.57	0.87 to 3.10	<0.001	69.0
Total sessions	<22	3	6.16	2.53	1.20 to 11.13	0.015	89.0
	≥22	5	1.83	0.36	1.12 to 2.54	<0.001	55.3
Total time (minutes)	≤960	4	4.24	1.43	1.43 to 7.05	0.003	88.5
	>960	4	2.03	0.41	1.23 to 2.84	<0.001	57.7
Total weeks	<10	4	4.82	1.35	2.17 to 7.48	<0.001	91.4
	≥10	4	1.51	0.30	0.92 to 2.11	<0.001	9.3

N = number of studies; g = effect size; SE = standard error; CI = confidence interval; *p* = level of significance; I^2 = heterogeneity; FMS = fundamental motor skills; PAMT = physical activity movement theme

Table 6. Intervention factor moderator analysis for balance

Moderator	Grouping	Effect-size statistics					Heterogeneity
		N	*g*	SE	95% CI	*p*	I^2 (%)
Intervention types	FMS	4	1.31	0.51	0.32 to 2.31	0.009	71.6
	PAMT	9	1.7	0.42	0.89 to 2.53	<0.001	79.3
Randomisation	Yes	9	1.79	0.52	0.77 to 2.82	<0.001	88.6
	No	4	1.31	0.31	0.71 to 1.92	<0.001	0
Session frequency	≤2	9	1.41	0.38	0.66 to 2.16	<0.001	73.6
	>2	4	1.92	0.60	0.74 to 3.10	0.001	82.0
Total sessions	<20	6	1.30	0.52	0.27 to 2.32	0.013	80.9
	≥20<40	3	1.82	0.33	1.17 to 2.46	<0.001	0
	≥40	4	1.85	0.60	0.68 to 3.01	0.002	77.2
Total time (minutes)	≤900	4	0.44	0.27	-0.10 to 0.98	0.110	28.6
	>900<1440	5	2.78	0.62	1.55 to 4.01	<0.001	66.8
	≥1440	4	1.50	0.36	0.77 to 2.22	<0.001	58.0
Total weeks	<10	6	1.3	0.52	0.27 to 2.32	0.013	80.9
	≥10<16	4	1.97	0.64	0.75 to 3.23	0.002	78.6
	≥16	3	1.66	0.31	1.06 to 2.56	<0.001	0

N = number of studies; *g* = effect size; SE = standard error; CI = confidence interval; *p* = level of significance; I^2 = heterogeneity; FMS = fundamental motor skills; PAMT = physical activity movement theme

Finally, the GRADE analyses are provided in Tables 8 - 11. According to the GRADE assessment, the certainty of the evidence is considered moderate to very low across outcomes and group comparisons. Imprecision: one level of downgrading occurred whenever <300 participants were available for comparison and/or if there was no clear direction of the effects.

DISCUSSION

This systematic review and meta-analyses revealed the beneficial effects of interventions on MPS in children aged four to thirteen with ASD, and medium-to-large effect sizes. The results have four important implications, specifically, (i) interventions provide children with ASD with the basic motor performance skill proficiency needed for more complex movements required in sports or advanced movement games; (ii) given the evidence that low MPS proficiency is associated with reduced physical activity participation, implementing MPS interventions may be at least part of a strategy to support children with ASD to develop MPS; (iii) different intervention strategies have varying levels of moderate to large effects on the development of MPS in children with ASD; (iv) FMS-themed instructional interventions are more likely to achieve greater improvements in MPS proficiency than physical activity movement-themed; (v) due

Table 7. The multivariate random-effect meta-regression results for training programming variables to predict intervention effects on balance

Covariate	Coefficient	SE	95% CI	*p* value
Randomisation	1.16	0.63	-0.07 to 2.38	0.65
Type of intervention	0.55	0.63	-0.68 to 1.78	0.38
Total weeks	-0.38	0.95	-2.24 to 1.47	0.69
Total sessions	3.99	1.52	1.01 to 6.98	0.009
Total time	-6.43	1.41	-9.19 to -3.66	<0.001
Session frequency	1.35	0.64	0.09 to 2.61	0.036

SE = Standard error; CI = Confidence interval; Bolded *p* value: significant ($p < 0.05$) effect of the training variables to predict intervention effects on balance

to the moderate to very low certainty of evidence-based on GRADE, this systematic review and the findings of the meta-analysis should be interpreted with care.

The multivariate meta-regression analysis revealed that the greatest improvements in balance were associated with long-term intervention approaches, involving a longer total time of intervention ($p < 0.001$), a greater number of sessions ($p < 0.01$) and higher weekly session frequency ($p < 0.05$). Moreover, the moderator analysis of balance also supports this finding. Indeed, interventions > 900 and < 1,440 minutes and >1,440 minutes of total intervention time induced significant improvements (ES = 2.78, $p < 0.001$; and ES = 1.50, $p < 0.001$; respectively). When the intervention exceeded 1,440 minutes, the effect was lower than when the intervention was between 900 and 1,440 minutes. Similarly, the moderator analysis revealed that total sessions > 20

Table 8. GRADE analyses of outcome measures

Outcome	Studies and PSS	Risk of bias in studies	Inconsistency	Indirectness	Imprecision	Certainty of evidence
Push-ups*	5 (*n* = 93)	ND	ND	ND	Downgraded	Very low
Jumping	3 (*n* = 63)	ND	ND	ND	Downgraded	Low
Bilateral coordination	5 (*n* = 93)	ND	Downgraded	ND	Downgraded	Low
Running speed and agility	5 (*n* = 106)	ND	ND	ND	Downgraded	Moderate
Overall MPS	8 (*n* = 178)	ND	Downgraded	ND	Downgraded	Low
Ball skills	9 (*n* = 250)	ND	Downgraded	ND	Downgraded	Low
Balance	13 (*n* = 310)	ND	ND	ND	ND	High

MPS = motor performance skills; PSS = pooled sample size; ND = Not downgraded. *Predominantly non-randomised papers (the GRADE starts on a low level of certainty)

Table 9. GRADE analyses of overall motor performance skill proficiency

Moderators	Studies and PSS	Risk of bias in studies	Inconsistency	Indirectness	Imprecision	Certainty of evidence
Intervention type						
FMS	5 (*n* = 123)	ND	Downgraded	ND	Downgraded	Low
PAMT	3 (*n* = 55)	ND	ND	ND	Downgraded	Moderate
Randomisation						
Yes	4 (*n* = 102)	ND	ND	ND	Downgraded	Moderate
No	4 (*n* = 76)	ND	Downgraded	ND	Downgraded	Very low
Session frequency						
≤2	5 (*n* = 94)	ND	Downgraded	ND	Downgraded	Low
>2	3 (*n* = 84)	ND	ND	ND	Downgraded	Moderate
Total sessions						
<22	3 (*n* = 56)	ND	Downgraded	ND	Downgraded	Very low
≥22	5 (*n* = 122)	ND	ND	ND	Downgraded	Moderate
Total time						
≤960	4 (*n* = 70)	ND	Downgraded	ND	Downgraded	Low
>960	4 (*n* = 108)	ND	ND	ND	Downgraded	Moderate
Total weeks						
<10	4 (*n* = 109)	ND	Downgraded	ND	Downgraded	Low
≥10	4 (*n* = 69)	ND	ND	ND	Downgraded	Moderate

FMS = fundamental movement skill; PSS = pooled sample size; ND = Not downgraded; PAMT = physical activity movement-theme

Table 10. GRADE analyses of ball skill moderators

Moderators	Studies and PSS	Risk of bias in studies	Inconsistency	Indirectness	Imprecision	Certainty of evidence
Intervention type						
FMS	5 (*n* = 169)	ND	Downgraded	ND	Downgraded	Low
PAMT	4 (*n* = 81)	ND	Downgraded	ND	Downgraded	Low
Randomisation						
Yes	6 (*n* = 194)	ND	Downgraded	ND	Downgraded	Low
No	3 (*n* = 56)	ND	Downgraded	ND	Downgraded	Very Low
Session frequency						
≤2	6 (*n* = 152)	ND	Downgraded	ND	Downgraded	Low
>2	3 (*n* = 98)	ND	Downgraded	ND	Downgraded	Low
Total sessions						
<22	6 (*n* = 137)	ND	Downgraded	ND	Downgraded	Low
≥22	3 (*n* = 113)	ND	Downgraded	ND	Downgraded	Low
Total time						
≤900	3 (*n* = 97)	ND	ND	ND	Downgraded	Moderate
>900<1440	3 (*n* = 96)	ND	ND	ND	Downgraded	Moderate
≥1440	3 (*n* = 57)	ND	Downgraded	ND	Downgraded	Low
Total weeks						
<10	5 (*n* = 137)	ND	Downgraded	ND	Downgraded	Low
≥10	4 (*n* = 113)	ND	Downgraded	ND	Downgraded	Low

FMS = fundamental movement skill; PSS = pooled sample size; ND = Not downgraded; PAMT = physical activity movement-theme

Table 11. GRADE analyses of balance moderators

Moderator	Studies and PSS	Risk of bias in studies	Inconsistency	Indirectness	Imprecision	Publication bias	Certainty of evidence
Intervention type							
FMS	4 (*n* = 105)	Not downgraded	Not downgraded	Not downgraded	Downgraded	Not downgraded	Moderate
PAMT	9 (*n* = 205)	Not downgraded	Downgraded	Not downgraded	Downgraded	Downgraded	Very low
Randomisation							
Yes	9 (*n* = 240)	Not downgraded	Downgraded	Not downgraded	Downgraded	Downgraded	Very low
No	4 (*n* = 70)	Not downgraded	Not downgraded	Not downgraded	Downgraded	Not downgraded	Moderate
Session frequency							
≤2	9 (*n* = 206)	Not downgraded	Not downgraded	Not downgraded	Downgraded	Downgraded	Low
>2	4 (*n* = 104)	Not downgraded	Downgraded	Not downgraded	Downgraded	Not downgraded	Low
Total sessions							
<20	6 (*n* = 151)	Not downgraded	Downgraded	Not downgraded	Downgraded	Downgraded	Very low
≥20<40	3 (*n* = 59)	Not downgraded	Not downgraded	Not downgraded	Downgraded	Not downgraded	Moderate
≥40	4 (*n* = 100)	Not downgraded	Downgraded	Not downgraded	Downgraded	Not downgraded	Low
Total Time							
≤900	4 (*n* = 111)	Not downgraded	Not downgraded	Not downgraded	Downgraded	Not downgraded	Moderate
>900<1440	5 (*n* = 97)	Not downgraded	Not downgraded	Not downgraded	Downgraded	Not downgraded	Moderate
≥1440	4 (*n* = 102)	Not downgraded	Not downgraded	Not downgraded	Downgraded	Not downgraded	Moderate
Total weeks							
<10	6 (*n* = 151)	Not downgraded	Downgraded	Not downgraded	Downgraded	Downgraded	Very low
≥10<16	4 (*n* = 96)	Not downgraded	Downgraded	Not downgraded	Downgraded	Not downgraded	Low
≥16	2 (*n* = 63)	Not downgraded	Not downgraded	Not downgraded	Downgraded	Not downgraded	Moderate

FMS = fundamental movement skill; PSS = pooled sample size; PAMT = physical activity movement-theme

< 40 (ES = 1.82, $p < 0.001$) and ≥ 40 (ES = 1.85, $p <.01$) induced greater improvements than < 20 total sessions. Moderator analysis of weekly frequency showed that > 2 sessions (ES = 1.92, $p < 0.001$) per week had a greater effect than ≤ 2 (ES = 1.41, $p < 0.001$). Moderator analysis for total weeks, $\geq 10 < 16$ weeks had the greatest effect size (see Table 5). Consistent with the physiological considerations of a dose-response principle with the expectation that longer interventions would lead to larger effect sizes, it was found that for the outcome balance, a minimum of 900 minutes, at least 20 sessions and more than two sessions per week optimally lead to improved balance. Interestingly, the effect size reduced slightly for balance when interventions were $\geq$ 1,440 minutes and ≥ 16 weeks (see Table 5), which may be due to decreased motivation and compliance (Logan et al., 2012), resulting from monotonous interventions and children losing some interest over time (Lai et al., 2014). Alternatively, there may have been sufficient adaption to the intervention, which then needed an increase in one of the intervention variables over time to maintain sufficient stimulus for similar effectiveness (Faigenbaum et al., 2014).

Moderator analysis for ball skills and overall MPS indicated the possible minimum dose (i.e., weekly session frequency, total sessions, total time, and total weeks) required for interventions to have a significant effect. For ball skills, intervention covariates resulting in the greatest effect includes weekly frequency of > 2 sessions (ES = 5.22, $p < 0.01$), < 22 sessions (ES = 3.76, $p < 0.01$), < 10 total weeks (ES = 3.76, $p < 0.01$) and lastly total time $> 900 <$ 1,440 minutes. Contrary to the moderator analysis for balance, overall MPS minimum dosages were relatively lower. For overall MPS, the following covariates were strongly favoured; ≤ 2 weekly sessions (ES = 3.50, $p < 0.001$), $<$ 22 total sessions (ES = 6.16, $p > 0.05$), ≤ 960 total minutes (ES = 4.24, $p <.001$), < 10 weeks (ES = 4.82, $p < 0.001$). Upon further investigation of the studies that contributed substantially to pooled data for the aforementioned favoured moderators for overall MPS, the interventions generally involved deliberate practice and learning the specific movement patterns assessed in pre- and post-testing. Therefore, participants in these studies may have experienced enhanced learning because of the learning effect (Adesope et al., 2017). Nevertheless, since there was significant improvement with a relatively low minimum dose for overall MPS, future studies may be necessary to clarify if a dose below 560 minutes is also effective.

Researchers should be aware that most studies did not report instruction time or the specific type of instruction, but rather the overall time of each intervention session. During an intervention session, time is associated with various tasks (i.e., demonstration of each task, reviewing the rules, and a warm-up and cool-down). Considering that most studies do not report a detailed outline of the intervention execution, it was not possible to delineate the total time of on-task engagement in each component of the intervention and the amount of instruction time. The relationship between intervention time and improvement in MPS may be clearer if actual instruction time was reported and used as a moderator variable.

It was not surprising to find positive results relating to the effects of different types of interventions on change in MPS proficiency. Whilst FMS-themed interventions were found to be more successful, physical activity movement-themed intervention approaches also led to positive improvements in MPS proficiency. The results are not unexpected from a motor development perspective, as specific FMS instruction led to more considerable improvements in MPS compared to physical activity movement-themed interventions. Dominant motor development theory suggests that specific practice of motor skills and movements will subsequently lead to improvements in motor performance (Adolph & Franchak, 2017; Magill & Anderson, 2017). Consequently, the specificity of training was supported through the FMS-specific instruction, which may also indicate an alignment of the intervention and the chosen method of MPS assessment. To fully capture the specific effect of an intervention, it is necessary to choose an assessment tool that has the capacity to measure the change that will result from the intervention. For example, the impact of a gymnastics intervention would best be measured by an assessment tool that measures gymnastic skills. Assessment tools such as TGMD-2 and BOT-2 are designed to measure global motor constructs and may not have the specificity or sensitivity to detect the changes in skills learnt or developed in a specific physical activity or sport. This may explain why the effect of physical activity movement-themed interventions on changes in MPS proficiency, while considerable, were not as large as the FMS-themed intervention type. Therefore, contextually relevant specific skill assessment tools that have the capacity to measure the change that will result from the intervention should be considered to accurately capture the effect of the intervention, rather than assessments that measure global motor constructs. Even though there is a need for assessment tools that have the capacity to measure the change that will result from an intervention with more specificity, a wide variety of interventions elicit substantial improvements in MPS proficiency in children with ASD.

Across the meta-analyses of specific MPS, both FMS and physical activity movement-themed interventions had a moderate to large effect size on those typical areas of impairment in children with ASD, such as object control (i.e., ball skills, bilateral coordination) and locomotor skills (i.e., jumping, running and agility) (Busti Ceccarelli et al., 2020; Gandotra et al., 2020). A possible explanation for this is that children with ASD involved in sequentially structured focused movement experiences help overcome the difficulties of learning skills that rely heavily on perceptual-action coupling strategies, such as ball catching (Ament et al., 2015; Izawa et al., 2012) and coordinated movements, such as hopping, dynamic balance, leaping and jumping. Of the 17 interventions, 11 included fitness training as a minor component of the FMS or physical activity movement-themed intervention. It is entirely plausible that the relative minor aspect of fitness training built into the intervention may have contributed to the positive effects, since in children with ASD, MPS proficiency has a positive association with health-related fitness (Bremer & Cairney, 2020; Tyler et al., 2014). Furthermore, in typically developing children, 10 to 15 minutes twice a week of fitness-type training, such as plyometrics and integrative neuromuscular training, has been shown to be more effective in improving MPS than traditional lessons alone (Faigenbaum et al., 2014; Sortwell et al., 2021). Considering that children with ASD often encounter difficulties in maintaining balance due to the problem of hypotonia (Lopez-Espejo et al., 2021), looseness of the muscles (Paquet et al., 2016), the improvement in strength (i.e., jumping, push-ups), neuromuscular performance, balance and agility skills in the studies, may also be contributed to aspects of fitness development embedded into the interventions. Though minor, improved neuromuscular performance resulting from the fitness training was possibly sufficient to have affected these improvements. Moreover, the meta-analyses of bilateral coordination, speed and agility, which are complex perceptual-motor skills, are strongly associated with speed and accuracy (Thelen et al., 1983). Even though speculative, one of the reasons for the improvement in these complex tasks may be the enhancement of the neuromuscular system to produce simultaneous coordination of the upper and lower limbs. It is also possible that the physical activity movement-themed interventions analysed in this study could force children with ASD to have a more organised perception related to actions, thus improving some perceptual-motor skills such as bilateral coordination and ball skills.

From a structural and pedagogical perspective, the findings are important as they further justify that deliberate and planned learning and development interventions are necessary to ensure motor behaviour change in children with ASD. Furthermore, this study indicates that children with ASD should be provided with deliberate practice opportunities to develop a broad range of MPS as these facilitate successful early involvement in sport (a prerequisite for prolonged engagement) (MacNamara et al., 2015). Thus, for children with ASD to effectively learn MPS, it is critical that quality programs are used with effective instruction (Graham et al., 2001), allowing greater access, broader spectrum and flexibility to support engagement in a wide variety of physical activities (Busti Ceccarelli et al., 2020; Gandotra et al., 2020).

Several outcomes emerging from this work may guide future research and MPS interventions for children with ASD. First, MPS interventions provide children with basic MPS competence necessary to perform more advanced movement. Second, the intervention's frequency, time and duration seem to affect the overall effectiveness of the intervention itself. For 73.33% of the reviewed studies, the frequency and dosage of each intervention resembled a format of a typical physical education or adapted physical education lesson; therefore, the research is transferrable from the lab to the field, making the intervention reproducible within an education setting. Third, given the evidence that both physical activity movement-themed (i.e., mini-basketball) and fundamental movement skill-focused interventions accelerate the development of MPS in children with ASD, the decision to implement a type of motor skill intervention in a formal setting (i.e., school) from those in this paper, may take into account student preferences (i.e., invoking student agency) to maximise engagement. Fourth, a non-significant effect of control groups (i.e., free play or regular physical activity) further supports that MPS proficiency does not develop naturally. This highlights the need for movement skills to be taught, practiced, and reinforced through developmentally appropriate, sequentially planned movement programs. Lastly, although all the included studies in this analysis were carried out over the last eight years, the limited number of interventions and the lack of theoretical foundations are worrying, and therefore further investigations are still needed.

Limitations

There are a few limitations inherent to the findings presented in this meta-analysis. First, many reviewed studies had small sample sizes and relatively poor descriptions of the intervention characteristics. Second, a small number had an overall low methodological quality, such as a failure to randomly assign participants, making it plausible to suggest that some of the very large positive effects on specific MPS from interventions for children with ASD may not generalise to all children with ASD. Furthermore, if children were not randomly assigned, they may have self-selected to participate based on task motivation. Third, considering that ASD is a highly heterogeneous disorder and most studies provided little information on the severity of ASD, the results of this meta-analysis may not apply to all children with ASD. Fourth, a small number of studies had an extreme effect size relative to the pool of studies and, therefore, could be considered outliers. Fifth, we did not perform an updated search of the literature after March 2022. However, many includable studies between March 2022 and October 2022, with potential to induce meaningful changes in main findings, are unlikely. Moreover, systematic review updates are required periodically. Therefore, the current novel systematic review is expected to be updated in the next five years. Finally, we may have encountered difficulty identifying relevant studies with null effects due to publication bias favouring articles reporting statistically significant intervention effects.

CONCLUSION

The analysis is critical for determining how to best allocate existing resources to improve physical education outcomes for children with ASD ensuring that interventions maximise the yield for potential benefits. The systematic review and meta-analysis findings suggest that FMS and physical activity movement-themed interventions could benefit children with ASD. Furthermore, this study highlights the importance of including deliberate MPS interventions that are planned and structured within the education setting for children with ASD. This is of the utmost importance because of the well-documented existence of lower MPS proficiency in children with ASD. Researchers must continue to manipulate the components of interventions (e.g., type of approach and amount of instruction time) to determine the optimal characteristics of effective interventions. Such characteristics include the length of the intervention, the type of instructional approach and the specific content of the curriculum so that other researchers can mirror the interventions. In addition, researchers are encouraged to report means and standard deviations for all intervention studies, to isolate the benefits of fitness training for children with ASD and the potential impact on MPS.

AUTHOR CONTRIBUTIONS

AS conceptualised the study. AS designed, performed, and analysed all the research. AS and KT extracted data. RRC reviewed and verified the analysed research. AS, KT, and PF were involved in the screening process. PF, KS, and HN provided critical feedback and manuscript input. AS, PF, KO, DM, KS, RF, RRC and HN wrote up the research while critically reviewing and editing the manuscript. All authors contributed to the article and approved the submitted version.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

DATA AVAILABILITY STATEMENT

The data supporting this review's findings are available on request from the corresponding author (Dr Andrew Sortwell).

ACKNOWLEDGEMENT

This work is supported by the Portuguese Foundation for Science and Technology, I.P., under project UIDB/04045/2020.

REFERENCES

Adesope, O. O., Trevisan, D. A., & Sundararajan, N. (2017). Rethinking the Use of Tests: A Meta-Analysis of Practice Testing. *Review of Educational Research*, *87*(3), 659-701. https://doi.org/10.3102/0034654316689306

Adolph, K. E., & Franchak, J. M. (2017). The development of motor behavior. Wiley interdisciplinary reviews. Cognitive science, *8*(1-2), 10.1002/wcs.1430. https://doi.org/10.1002/wcs.1430

Allen, K. A., Bredero, B., Van Damme, T., Ulrich, D. A., & Simons, J. (2017). Test of Gross Motor Development-3 (TGMD-3) with the Use of Visual Supports for Children with Autism Spectrum Disorder: Validity and Reliability. *Journal of Autism and Developmental Disorders*, *47*(3), 813-833. https://doi.org/10.1007/s10803-016-3005-0

Ament, K., Mejia, A., Buhlman, R., Erklin, S., Caffo, B., Mostofsky, S., & Wodka, E. (2015). Evidence for specificity of motor impairments in catching and balance in children with autism. *Journal of Autism and Developmental Disorders*, *45*(3), 742-751. https://doi.org/10.1007/s10803-014-2229-0

Amonkar, N., Su, W.-C., Bhat, A. N., & Srinivasan, S. M. (2021). Effects of Creative Movement Therapies on Social Communication, Behavioral-Affective, Sensorimotor, Cognitive, and Functional Participation Skills of Individuals With Autism Spectrum Disorder: A Systematic Review [Systematic Review]. *Frontiers in Psychiatry*, *12*. https://doi.org/10.3389/fpsyt.2021.722874

Ansari, S., Hosseinkhanzadeh, A. A., AdibSaber, F., Shojaei, M., & Daneshfar, A. (2021). The Effects of Aquatic Versus Kata Techniques Training on Static and Dynamic Balance in Children with Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, *51*(9), 3180-3186. https://doi.org/10.1007/s10803-020-04785-w

Barnett, L., Stodden, D., E. Cohen, K., Smith, J., Lubans, D., Lenoir, M., Iivonen, S., Miller, A., Laukkanen, A., Dudley, D., Lander, N., Brown, H., & Morgan, P. (2016). Fundamental Movement Skills: An Important Focus. *Journal of Teaching Physical Education*, *35(3)*, 219 - 225. https://doi.org/10.1123/jtpe.2014-0209

Barnett, L. M., van Beurden, E., Morgan, P. J., Brooks, L. O., & Beard, J. R. (2009). Childhood motor skill proficiency as a predictor of adolescent physical activity. *Jounral of Adolescent Health*, *44*(3), 252-259. https://doi.org/10.1016/j.jadohealth.2008.07.004

Behringer, M., Heede, A., Matthews, M., & Mester, J. (2011). Effects of Strength Training on Motor Performance Skills in Children and Adolescents: A Meta-Analysis. *Pediatric Exercise Science*, *23(2)*, 186-206. https://doi.org/10.1123/pes.23.2.186

Berkeley, S. L., Zittel, L. L., Pitney, L. V., & Nichols, S. E. (2001). Locomotor and Object Control Skills of Children Diagnosed with Autism. *Adapted Physical Activity Quarterly*, *18*(4), 405-416. https://doi.org/10.1123/apaq.18.4.405

Bishop, J. C., & Pangelinan, M. (2018). Motor skills intervention research of children with disabilities. *Research in Developmental Disabilities*, *74*, 14-30. https://doi.org/https://doi.org/10.1016/j.ridd.2017.11.002

Bremer, E., & Cairney, J. (2016). Fundamental Movement Skills and Health-Related Outcomes: A Narrative Review of Longitudinal and Intervention Studies Targeting Typically Developing Children. *American Journal of Lifestyle Medicine*, *12*(2), 148-159. https://doi.org/10.1177/1559827616640196

Bremer, E., & Cairney, J. (2020). Adaptive Behavior Moderates Health-Related Pathways in Children with Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, *50*(2), 491-499. https://doi.org/10.1007/s10803-019-04277-6

Broder-Fingert, S., Brazauskas, K., Lindgren, K., Iannuzzi, D., & Van Cleave, J. (2014). Prevalence of overweight and obesity in a large clinical sample of children with autism. *Academic Pediatrics*, *14*(4), 408-414. https://doi.org/10.1016/j.acap.2014.04.004

Bruininks-Oseretsky, R. (1978). Test of motor proficiency: Examiner's manual. *Circle Pines, MN: American Guidance Service*.

Busti Ceccarelli, S., Ferrante, C., Gazzola, E., Marzocchi, G. M., Nobile, M., Molteni, M., & Crippa, A. (2020). Fundamental Motor Skills Intervention for Children with Autism Spectrum Disorder: A 10-Year Narrative Review. *Children (Basel)*, *7*(11), 250. https://doi.org/10.3390/children7110250

Cai, K. L., Wang, J. G., Liu, Z. M., Zhu, L. N., Xiong, X., Klich, S., Maszczyk, A., & Chen, A. G. (2020). Mini-Basketball Training Program Improves Physical Fitness and Social Communication in Preschool Children with Autism Spectrum Disorders. *Journal of Human Kinetics*, *73(1)*, 267-278. https://doi.org/10.2478/hukin-2020-0007

Case-Smith, J., Weaver, L. L., & Fristad, M. A. (2015). A systematic review of sensory processing interventions for children with autism spectrum disorders. *Autism*, *19*(2), 133-148. https://doi.org/10.1177/1362361313517762

Case, L., & Yun, J. (2019). The Effect of Different Intervention Approaches on Gross Motor Outcomes of Children With Autism Spectrum Disorder: A Meta-Analysis. *Adapt Physical Activity Quarterly*, *36*(4), 501-526. https://doi.org/10.1123/apaq.2018-0174

Cashin, A. G., & McAuley, J. H. (2020). Clinimetrics: Physiotherapy Evidence Database (PEDro) Scale. *Journal of Physiotherapy*, *66*(1), 59. https://doi.org/https://doi.org/10.1016/j.jphys.2019.08.005

Chaput, J.-P., Willumsen, J., Bull, F., Chou, R., Ekelund, U., Firth, J., Jago, R., Ortega, F. B., & Katzmarzyk, P. T. (2020). 2020 WHO guidelines on physical activity and sedentary behaviour for children and adolescents aged 5–17 years: summary of the evidence. *International Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 141. https://doi.org/10.1186/s12966-020-01037-z

Chu, C. H., Tsai, C. L., Chen, F. C., Sit, C. H. P., Chen, P. L., & Pan, C. Y. (2020). The role of physical activity and body-related perceptions in motor skill competence of adolescents with autism spectrum disorder. *Disability Rehabilitation*, *42*(10), 1373-1381. https://doi.org/10.1080/09638288.2018.1526334

Coffey, C., Sheehan, D., Faigenbaum, A. D., Healy, S., Lloyd, R. S., & Kinsella, S. (2021). Comparison of fitness levels between elementary school children with autism spectrum disorder and age-matched neurotypically developing children. *Autism Research*, *14*(9), 2038-2046. https://doi.org/https://doi.org/10.1002/aur.2559

Croen, L. A., Zerbo, O., Qian, Y., Massolo, M. L., Rich, S., Sidney, S., & Kripke, C. (2015). The health status of adults on the autism spectrum. *Autism*, *19*(7), 814-823. https://doi.org/10.1177/1362361315577517

Cuesta-Gómez, J. L., De la Fuente-Anuncibay R, R., Vidriales-Fernández, R., & Ortega-Camarero, M. T. (2022). The quality of life of people with ASD through physical activity and sports. *Heliyon*, *8*(3), e09193. https://doi.org/https://doi.org/10.1016/j.heliyon.2022.e09193

de Morton, N. A. (2009). The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. *Aust J Physiother*, *55*(2), 129-133. https://doi.org/10.1016/s0004-9514(09)70043-1

Dong, L., Shen, B., Pang, Y., Zhang, M., Xiang, Y., Xing, Y., Wright, M., Li, D., & Bo, J. (2021). FMS Effects of a Motor Program for Children With Autism Spectrum Disorders. *Perceptual Motor Skills*, *128*(4), 1421-1442. https://doi.org/10.1177/00315125211010053

Drevon, D., Fursa, S. R., & Malcolm, A. L. (2017). Intercoder Reliability and Validity of WebPlotDigitizer in Extracting Graphed Data. *Behav Modif*, *41*(2), 323-339. https://doi.org/10.1177/0145445516673998

Duncan, M. J., Hall, C., Eyre, E., Barnett, L. M., & James, R. S. (2021). Pre-schoolers fundamental movement skills predict BMI, physical activity, and sedentary behavior: A longitudinal study. *Scandinavian Journal of Medicine & Science in Sports*, *31 Suppl 1*, 8-14. https://doi.org/10.1111/sms.13746

Duval, S., & Tweedie, R. (2000). Trim and fill: A simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. *Biometrics*, *56*(2), 455-463. https://doi.org/10.1111/j.0006-341x.2000.00455.x

Egger, M., Smith, G. D., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. *BMJ*, *315*(7109), 629-634. https://doi.org/10.1136/bmj.315.7109.629

Ekman, R., Fletcher, A., Giota, J., Eriksson, A., Thomas, B., & Bååthe, F. (2022). A Flourishing Brain in the 21st Century: A Scoping Review of the Impact of Developing Good Habits for Mind, Brain, Well-Being, and Learning. *Mind, Brain, and Education*, *16*(1), 13-23. https://doi.org/https://doi.org/10.1111/mbe.12305

Elliott, L. K., Weiss, J. A., & Lloyd, M. (2021). Beyond the Motor Domain: Exploring the Secondary Effects of a Fundamental Motor Skill Intervention for Children With Autism Spectrum Disorder. *Adapted Physical Activity Quarterly*, *38*(2), 195-214. https://doi.org/10.1123/apaq.2020-0024

Faigenbaum, A. D., Myer, G. D., Farrell, A., Radler, T., Fabiano, M., Kang, J., Ratamess, N., Khoury, J., & Hewett, T. E. (2014). Integrative neuromuscular training and sex-specific fitness performance in 7-year-old children: an exploratory investigation. *Journal of Athletic Training*, *49*(2), 145-153. https://doi.org/10.4085/1062-6050-49.1.08

Felzer-Kim, I. T., & Hauck, J. L. (2020). How Much Instructional Time Is Necessary? Mid-intervention Results of Fundamental Movement Skills Training Within ABA Early Intervention Centers. *Frontiers in Integrative Neuroscience*, *14*(24). https://doi.org/10.3389/fnint.2020.00024

Fortuna, R. J., Robinson, L., Smith, T. H., Meccarello, J., Bullen, B., Nobis, K., & Davidson, P. W. (2016). Health Conditions and Functional Status in Adults with Autism: A Cross-Sectional Evaluation. *Journal of General Internal Medicine*, *31*(1), 77-84. https://doi.org/10.1007/s11606-015-3509-x

Gandotra, A., Kotyuk, E., Szekely, A., Kasos, K., Csirmaz, L., & Cserjesi, R. (2020). Fundamental movement skills in children with autism spectrum disorder: A systematic review. *Research in Autism Spectrum Disorders*, *78*. https://doi.org/10.1016/j.rasd.2020.101632

García-Hermoso, A., Ramírez-Campillo, R., & Izquierdo, M. (2019). Is Muscular Fitness Associated with Future Health Benefits in Children and Adolescents? A Systematic Review and Meta-Analysis of Longitudinal Studies. *Sports Med*, *49*(7), 1079-1094. https://doi.org/10.1007/s40279-019-01098-6

Green, D., Charman, T., Pickles, A., Chandler, S., Loucas, T., Simonoff, E., & Baird, G. (2009). Impairment in movement skills of children with autistic spectrum disorders. *Dev Med Child Neurol*, *51*(4), 311-316. https://doi.org/10.1111/j.1469-8749.2008.03242.x

Guyatt, G., Oxman, A. D., Akl, E. A., Kunz, R., Vist, G., Brozek, J., Norris, S., Falck-Ytter, Y., Glasziou, P., deBeer, H., Jaeschke, R., Rind, D., Meerpohl, J., Dahm, P., & Schünemann, H. J. (2011). GRADE guidelines: 1. Introduction—GRADE evidence profiles and summary of findings tables. *Journal of Clinical Epidemiology*, *64*(4), 383-394. https://doi.org/10.1016/j.jclinepi.2010.04.026

Hassani, F., Shahrbanian, S., Shahidi, S. H., & Sheikh, M. (2022). Playing games can improve physical performance in children with autism. *International Journal of Developmental Disabilities*, *68*(2), 219-226. https://doi.org/10.1080/20473869.2020.1752995

Higgins, J. P., & Thompson, S. G. (2002). Quantifying heterogeneity in a meta-analysis. *Statistics in Medicine*, *21*(11), 1539-1558. https://doi.org/10.1002/sim.1186

Higgins JPT, T. J., Chandler J, Cumpston M, Li T, Page MJ, Welch VA. (2022). *Cochrane Handbook for Systematic Reviews of Interventions version 6.3*. Cochrane.

Hill, A. P., Zuckerman, K. E., & Fombonne, E. (2015). Obesity and Autism. *Pediatrics*, *136*(6), 1051-1061. https://doi.org/10.1542/peds.2015-1437

Hilton, C., Wente, L., Lavesser, P., Ito, M., Reed, C., & Herzberg, G. (2007). Relationship between motor skill impairment and severity in children with Asperger Syndrome. *Research in Autism Spectrum Disorders*, *1(4)*, 339-349. https://doi.org/10.1016/j.rasd.2006.12.003

Holfelder, B., & Schott, N. (2014). Relationship of fundamental movement skills and physical activity in children and adolescents: A systematic review. *Psychology of Sport and Exercise*, *15(4)*, 382-391. https://doi.org/10.1016/j.psychsport.2014.03.005

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Medicine & Science in Sports & Exercise*, *41*(1), 3-12. https://doi.org/10.1249/MSS.0b013e31818cb278

Hozo, S. P., Djulbegovic, B., & Hozo, I. (2005). Estimating the mean and variance from the median, range, and the size of a sample. *BMC Medical Research Methodology*, *5*(13). https://doi.org/10.1186/1471-2288-5-13

Huang, J., Du, C., Liu, J., & Tan, G. (2020). Meta-Analysis on Intervention Effects of Physical Activities on Children and Adolescents with Autism. *International Journal Environmental Research and Public Health*, *17*(6). https://doi.org/10.3390/ijerph17061950

Izawa, J., Pekny, S. E., Marko, M. K., Haswell, C. C., Shadmehr, R., & Mostofsky, S. H. (2012). Motor Learning Relies on Integrated Sensory Inputs in ADHD, but Over-Selectively on Proprioception in Autism Spectrum Conditions. *Autism Research*, *5*(2), 124-136. https://doi.org/https://doi.org/10.1002/aur.1222

Janssen, I., & LeBlanc, A. G. (2010). Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity*, *7*(40). https://doi.org/10.1186/1479-5868-7-40

Ketcheson, L., Hauck, J., & Ulrich, D. (2017). The effects of an early motor skill intervention on motor skills, levels of physical activity, and socialisation in young children with autism spectrum disorder: A pilot study. *Autism*, *21*(4), 481-492. https://doi.org/10.1177/1362361316650611

Kim, Y., Todd, T., Fujii, T., Lim, J. C., Vrongistinos, K., & Jung, T. (2016). Effects of Taekwondo intervention on balance in children with autism spectrum disorder. *Journal of Exercercise Rehabilitation*, *12*(4), 314-319. https://doi.org/10.12965/jer.1632634.317

Lai, S. K., Costigan, S. A., Morgan, P. J., Lubans, D. R., Stodden, D. F., Salmon, J., & Barnett, L. M. (2014). Do school-based interventions focusing on physical activity, fitness, or fundamental movement skill competency produce a sustained impact in these outcomes in children and adolescents? A systematic review of follow-up studies. *Sports Medicine*, *44*(1), 67-79. https://doi.org/10.1007/s40279-013-0099-9

Lang, R., Koegel, L. K., Ashbaugh, K., Regester, A., Ence, W., & Smith, W. (2010). Physical exercise and individuals with autism spectrum disorders: A systematic review. Research in Autism Spectrum Disorders, *4*(4), 565-576. https://doi.org/https://doi.org/10.1016/j.rasd.2010.01.006

Larsen, M. N., Nielsen, C. M., Ørntoft, C. Ø., Randers, M. B., Manniche, V., Hansen, L., Hansen, P. R., Bangsbo, J., & Krustrup, P. (2017). Physical Fitness and Body Composition in 8–10-Year-Old Danish Children Are Associated With Sports Club Participation. *The Journal of Strength & Conditioning Research*, *31*(12), 3425-3434. https://doi.org/10.1519/jsc.0000000000001952

Liang, X., Li, R., Wong, S. H. S., Sum, R. K. W., & Sit, C. H. P. (2020). Accelerometer-measured physical activity levels in children and adolescents with autism spectrum disorder: A systematic review. *Preventive Medicine Reports*, *19*, 101147. https://doi.org/https://doi.org/10.1016/j.pmedr.2020.101147

Logan, S. W., Robinson, L. E., Wilson, A. E., & Lucas, W. A. (2012). Getting the fundamentals of movement: a meta-analysis of the effectiveness of motor skill interventions in children. *Child Care Health Development*, *38*(3), 305-315. https://doi.org/10.1111/j.1365-2214.2011.01307.x

Lopez-Diaz, J. M., Felgueras Custodio, N., & Garrote Camarena, I. (2021). Football as an Alternative to Work on the Development of Social Skills in Children with Autism Spectrum Disorder with Level 1. *Behavioral Science (Basel, Switzerland)*, *11*(11), 159. https://doi.org/10.3390/bs11110159

Lopez-Espejo, M. A., Nuñez, A. C., Moscoso, O. C., & Escobar, R. G. (2021). Clinical characteristics of children affected by autism spectrum disorder with and without generalised hypotonia. *European Journal of Pediatrics*, *180*(10), 3243-3246. https://doi.org/10.1007/s00431-021-04038-7

Lourenco, C., Esteves, D., Corredeira, R., & Seabra, A. (2015). The effect of a trampoline-based training program on the muscle strength of the inferior limbs and motor proficiency in children with autism spectrum disorders. *Journal of Physical Education and Sport*, *15(3)*, 592-597. https://doi.org/10.7752/jpes.2015.03089

Lourenco, C., Esteves, D., Corredeira, R., & Seabra, A. (2016). The Efficacy of a Trampoline Training Program on the Motor Proficiency of Children with Autism Spectrum Disorder. *Brazilian Journal of Special Education*, *22*(1), 39-48. https://doi.org/https://doi.org/10.1590/S1413-65382216000100004

Lucas, B. R., Elliott, E. J., Coggan, S., Pinto, R. Z., Jirikowic, T., McCoy, S. W., & Latimer, J. (2016). Interventions to improve gross motor performance in children with neurodevelopmental disorders: a meta-analysis. *BMC Pediatrics*, *16*(1), 193. https://doi.org/10.1186/s12887-016-0731-6

MacDonald, M., Esposito, P., & Ulrich, D. (2011). The physical activity patterns of children with autism. *BMC Research Notes*, *4*(1), 422. https://doi.org/10.1186/1756-0500-4-422

MacNamara, Á., Collins, D., & Giblin, S. (2015). Just let them play? Deliberate preparation as the most appropriate foundation for lifelong physical activity [Opinion]. *Frontiers in Psychology*, *6*, 1548. https://doi.org/10.3389/fpsyg.2015.01548

Maher, C. G., Sherrington, C., Herbert, R. D., Moseley, A. M., & Elkins, M. (2003). Reliability of the PEDro Scale for Rating Quality of Randomized Controlled Trials. *Physical therapy*, *83*(8), 713-721. https://doi.org/10.1093/ptj/83.8.713

Magill R. A. & Anderson D. I. (2017). *Motor learning and control: Concepts and applications* (Eleventh). McGraw-Hill Education.

Methley, A. M., Campbell, S., Chew-Graham, C., McNally, R., & Cheraghi-Sohi, S. (2014). PICO, PICOS and SPIDER: a comparison study of specificity and sensitivity in three search tools for qualitative systematic reviews. *BMC Health Services Research*, *14*(1), 579. https://doi.org/10.1186/s12913-014-0579-0

Mitchell, J. (2019). Physical Inactivity in Childhood from Preschool to Adolescence. *ACSM's Health & Fitness Journal*, *23*(5), 21-25. https://doi.org/10.1249/fit.0000000000000507

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The, P. G. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLOS Medicine*, *6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097

Moseley, A. M., Herbert, R. D., Sherrington, C., & Maher, C. G. (2002). Evidence for physiotherapy practice: a survey of the Physiotherapy Evidence Database (PEDro). *Australian Journal of Physiotherapy, 48*(1), 43-49. https://doi.org/10.1016/s0004-9514(14)60281-6

Najafabadi, M. G., Sheikh, M., Hemayattalab, R., Memari, A. H., Aderyani, M. R., & Hafizi, S. (2018). The effect of SPARK on social and motor skills of children with autism. *Pediatrics and Neonatology*, *59*(5), 481-487. https://doi.org/10.1016/j.pedneo.2017.12.005

Pan, C. Y., Chu, C. H., Tsai, C. L., Sung, M. C., Huang, C. Y., & Ma, W. Y. (2017). The impacts of physical activity intervention on physical and cognitive outcomes in children with autism spectrum disorder. *Autism*, *21*(2), 190-202. https://doi.org/10.1177/1362361316633562

Pan, C. Y., Tsai, C. L., Chen, F. C., Chow, B. C., Chen, C. C., & Chu, C. H. (2021). Physical and Sedentary Activity Patterns in Youths with Autism Spectrum Disorder. *International Journal of Environmental Research and Public Health*, *18*(4), 1739. https://doi.org/10.3390/ijerph18041739

Pan, C. Y., Tsai, C. L., & Chu, C. H. (2009). Fundamental movement skills in children diagnosed with autism spectrum disorders and attention deficit hyperactivity disorder. *Journal of Autism and Developmental Disorders*, *39*(12), 1694-1705. https://doi.org/10.1007/s10803-009-0813-5

Paquet, A., Olliac, B., Bouvard, M. P., Golse, B., & Vaivre-Douret, L. (2016). The Semiology of Motor Disorders in Autism Spectrum Disorders as Highlighted from a Standardised Neuro-Psychomotor Assessment. *Frontiers in Psychology*, *7*, 1292. https://doi.org/10.3389/fpsyg.2016.01292

Poitras, V. J., Gray, C. E., Borghese, M. M., Carson, V., Chaput, J.-P., Janssen, I., Katzmarzyk, P. T., Pate, R. R., Gorber, S. C., Kho, M. E., Sampson, M., & Tremblay, M. S. (2016). Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth. *Applied Physiology, Nutrition, and Metabolism*, *41*(6 Suppl 3), S197–S239. https://doi.org/10.1139/apnm-2015-0663

Rafiei, H., Sheikh, M., Najafabadi, M. G., Saghaei, B., Naghdi, N., & Dewey, D. (2021). The Effects of Physical Activity and Exergaming on Motor Skills and Executive Functions in Children with Autism Spectrum Disorder. *Games for Health Journal*, *10*(1), 33-42. https://doi.org/10.1089/g4h.2019.0180

Rostami Haji Abadi, M., Zheng, Y., Wharton, T., Dell, C., Vatanparast, H., Johnston, J., & Kontulainen, S. (2021). Children with Autism Spectrum Disorder Spent 30 Min Less Daily Time in Moderate-to-Vigorous Physical Activity than Typically Developing Peers: a Meta-Analysis of Cross-sectional Data. *Review Journal of Autism and Developmental Disorders.* https://doi.org/10.1007/s40489-021-00262-x

Sarabzadeh, M., Azari, B. B., & Helalizadeh, M. (2019). The effect of six weeks of Tai Chi Chuan training on the motor skills of children with Autism Spectrum Disorder. *Journal of Bodywork and Movement Therapies*, *23*(2), 284-290. https://doi.org/10.1016/j.jbmt.2019.01.007

Shi, L., & Lin, L. (2019). The trim-and-fill method for publication bias: practical guidelines and recommendations based on a large database of meta-analyses. *Medicine (Baltimore)*, *98*(23), e15987. https://doi.org/10.1097/md.0000000000015987

Skrede, T., Steene-Johannessen, J., Anderssen, S. A., Resaland, G. K., & Ekelund, U. (2019). The prospective association between objectively measured sedentary time, moderate-to-vigorous physical activity and cardiometabolic risk factors in youth: a systematic review and meta-analysis. *Obesity Reviews*, *20*(1), 55-74. https://doi.org/10.1111/obr.12758

Solum, M., Lorås, H., & Pedersen, A. V. (2020). A Golden Age for Motor Skill Learning? Learning of an Unfamiliar Motor Task in 10-Year-Olds, Young Adults, and Adults, When Starting From Similar Baselines [Original Research]. *Frontiers in Psychology*, *11,* 538. https://doi.org/10.3389/fpsyg.2020.00538

Sortwell, A., Newton, M., Marinho, D., Ferraz, R., & Perlman, D. (2021). The Effects of an Eight Week Plyometric-based Program on Motor Performance Skills and Muscular Power in 7-8-Year-Old Primary School Students. *International Journal of Kinesiology and Sports Science*, *9*(4), 1-12. https://doi.org/10.7575/aiac.ijkss.v.9n.4p.1

Sortwell, A., Behringer, M., Granacher, U., Trimble, K., Forte, P., P. Neiva, H., Clemente-Suárez, V., Ramirez-Campillo, R., Konukman, F., Tufekcioglu, E., Filizn, B., Branquinho, L., Ferraz, R., Sadeghi, H., & Jaime Arroyo-Toledo, J. (2022). Advancing Sports Science and Physical Education Research Through a Shared Understanding of the Term Motor Performance Skills: A Scoping Review with Content Analysis. *International Journal of Kinesiology and Sports Science*, *10*(3), 18-27. https://doi.org/10.7575/aiac.ijkss.v.10n.3p.18

Thelen, E., Ridley-Johnson, R., & Fisher, D. M. (1983). Shifting patterns of bilateral coordination and lateral dominance in the leg movements of young infants. *Developmental Psychobiology*, *16*(1), 29-46. https://doi.org/10.1002/dev.420160105

Tremblay, M. S., Carson, V., Chaput, J.-P., Gorber, S. C., Dinh, T., Duggan, M., Faulkner, G., Gray, C. E., Gruber, R., Janson, K., Janssen, I., Katzmarzyk, P. T., Kho, M. E., Latimer-Cheung, A. E., LeBlanc, C., Okely, A. D., Olds, T., Pate, R. R., Phillips, A., Poitras, V. J., Rodenburg, S., Sampson, M., Saunders, T. J., Stone, J. A., Stratton, G., Weiss, S. K., & Zehr, L. (2016). Canadian 24-Hour Movement Guidelines for Children and Youth: An Integration of Physical Activity, Sedentary Behaviour, and Sleep. *Applied Physiology, Nutrition, and Metabolism*, *41*(6 (Suppl. 3)), S311-S327. https://doi.org/10.1139/apnm-2016-0151

Tyler, K., MacDonald, M., & Menear, K. (2014). Physical activity and physical fitness of school-aged children and youth with autism spectrum disorders. *Autism Research and Treatment*, *2014*, 312163. https://doi.org/10.1155/2014/312163

Viechtbauer, W., & Cheung, M. W. (2010). Outlier and influence diagnostics for meta-analysis. *Research Synthesis Methods*, 1(2), 112–125. https://doi.org/10.1002/jrsm.11

Vlahov, E., Baghurst, T. M., & Mwavita, M. (2014). Preschool motor development predicting high school health-related physical fitness: a prospective study. *Perceptual and Motor Skills*, *119*(1), 279-291. https://doi.org/10.2466/10.25.PMS.119c16z8

Whyatt, C. P., & Craig, C. M. (2012). Motor skills in children aged 7-10 years, diagnosed with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *42*(9), 1799-1809. https://doi.org/10.1007/s10803-011-1421-8

Xin, F., Chen, S.-T., Clark, C., Hong, J.-T., Liu, Y., & Cai, Y.-J. (2020). Relationship between Fundamental Movement Skills and Physical Activity in Preschool-Aged Children: A Systematic Review. *International Journal of Environmental Research and Public Health*, *17*(10), 3566. https://doi.org/10.3390/ijerph17103566

Yamato, T. P., Maher, C., Koes, B., & Moseley, A. (2017). The PEDro scale had acceptably high convergent validity, construct validity, and interrater reliability in evaluating methodological quality of pharmaceutical trials. *Journal of Clinical Epidemiology*, *86*, 176-181. https://doi.org/10.1016/j.jclinepi.2017.03.002

Zamani Jam, A., Talab, R. H., Sheikh, M., Torabi, F., & Rafie, F. (2018). The effect of 16 weeks gymnastic training on social skills and neuropsychiatric functions of autistic children. *Sport Sciences for Health*, *14*(1), 209-214. https://doi.org/10.1007/s11332-017-0417-y