

SYSTEMATIC REVIEW

Exploring the Relationship Between Fundamental Motor Skill Interventions and Physical Activity Levels in Children: A Systematic Review and Meta-analysis

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Abstract

Background Physical activity provides many health benefits, yet few children meet the physical activity recommendations. In school-age children, low proficiency in fundamental movement skills (FMS) is associated with low physical activity (PA). It is unknown if the same relationship exists in pre-schoolers (aged 3–5 years).

Objectives The aims of this review were to firstly evaluate interventions for improving FMS and PA levels in children aged 3–5 years and 5–12 years, and secondly to determine, where possible, if there is a similar relationship between change in FMS and change in PA across both age groups.

Methods A systematic search of electronic databases was conducted up until 20 July 2017. Controlled trials that implemented an FMS/PA intervention and measured PA levels (objective/subjective) and FMS (objective) in healthy children between the ages of 3 and 12 years were included. Sub-analysis was conducted based on the type of intervention (teacher-led [TL] or teacher educated), sessions per week (< 3 or ≥ 3) and age group.

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Results Search terms yielded 17,553 articles, of which 18 met the inclusion criteria. There was significant improvement in FMS with TL interventions of three or more sessions per week (standardised mean difference = 0.23 [0.11–0.36]; $p = 0.0002$). In TL interventions, there was a strong negative correlation between moderate–vigorous physical activity (MVPA) and sedentary behaviour (SB) ($r = -0.969$; $p = 0.031$).

Conclusions There are limited studies measuring both FMS and PA following an FMS intervention, especially in school-aged children. Results indicate that training pre-schoolers at least three times a week in FMS can improve proficiency, increase intensity of PA, and reduce SB, possibly helping to reduce the burden of childhood obesity and its associated health risks.

Key Points

Pre-schoolers demonstrate a significant improvement in fundamental motor skill proficiency following teacher-led interventions that are delivered at least three sessions per week. The effect of teacher-led interventions in school-age children requires further research.

There is a significant negative relationship between moderate to vigorous physical activity (MVPA) and sedentary behaviours, indicating that pre-schoolers who have higher levels of MVPA have lower levels of sedentary behaviour.

Results of this meta-analysis may help guide fundamental motor skill training for children in the future.

1 Introduction

Childhood obesity is a growing problem. Globally, there are 41 million children under the age of 5 years who are classified as overweight or obese. This affects countries of all wealth levels but is particularly more prevalent in urban settings [1]. Worldwide, the prevalence of overweight and obesity in under 20 s exceeds 40% [2]. The World Health Organisation attributes this high number to a trend towards decreased physical activity (PA) levels due to the increasingly sedentary nature of many forms of recreation time [3]. According to Tremblay et al., overall grades for children's PA in a worldwide report card were low/poor [4]. Furthermore, in a 2005 systematic review, within most countries, PA levels were lower and sedentary behaviour (SB) higher in overweight compared with normal weight youth [5]. More recently, Timmons et al. reported that in children under 4 years of age, PA is positively associated with "improved measures of adiposity" [6]. More information is needed on effective ways to encourage younger children to move, as the negative effects of inactivity can be lifelong with a strong correlation between childhood and adult obesity [7].

Regular PA is vital for the normal growth and development of pre-schoolers through to adolescents [8, 9]. Despite inconsistent data on the relationship between PA and overweight/obesity, studies on habitual physical activity indicate that children who are less active are more likely to become overweight or obese [6, 8, 10, 11]. However, these studies are based on school-aged children, and to the authors' knowledge there is little information on this relationship in pre-schoolers. Along with reduced obesity, the health benefits associated with children being physically active are numerous and spread across multiple areas of health, including improved cardiometabolic health indicators [6], reduced depressive symptoms, improved cognitive development and psychosocial well-being [12] as well as increased bone mineral density [13].

Fundamental motor skills (FMS) are the building blocks for the complex movement sequences required for a range of sport and recreational activities including playground games and organised sport [14]. They can be broken down into two main categories: locomotor skills (LS) and object control skills (OS). LS require the fluid coordination of the body as it moves in one direction or another and includes skills such as running, galloping, jumping, hopping, leaping and sideways skipping [15]. OS require the efficient control of another object such as a bat or ball and includes skills such as throwing, catching, kicking, rolling, striking and dribbling [15]. Balance is also identified as a measure

of FMS [16]. The critical time to develop these skills is in early childhood as movement patterns are being developed [17] and before the school-age years, when children start to participate in the games and sports that will require them to use these skills.

Current evidence suggests that overweight/obese children tend to be less proficient in FMS and have lower levels of PA participation than their healthy weight counterparts [18]. Furthermore, FMS proficiency is associated with better health outcomes in children, such as lower body mass index and increased aerobic fitness [19]. A longitudinal study [20] exploring the effects of early motor skill proficiency into adulthood found a strong positive association between FMS development at age 6 years and time spent in leisure time PA at age 26 years. This indicates the importance of effective interventions being implemented to allow children to develop their FMS early, reducing their risk of cardiovascular and metabolic diseases through continued PA into adolescence and adulthood.

Studies suggest that in both pre-schoolers [21] and school-aged children [14] there is a positive relationship between FMS competence and increased levels of PA; however, there are no systematic reviews or meta-analyses, to our knowledge, that have synthesised these results to identify if a relationship does in fact exist between FMS and PA following an intervention. A recent systematic review by Logan et al. found relationships between FMS and PA in early through to late childhood in cross-sectional studies [22]. Morgan et al. found that FMS interventions work to increase FMS proficiency in children [23], with a more recent meta-analysis supporting this and reporting that PA interventions improve FMS in pre-schoolers; however, the authors were unable to report on any relationship between PA and FMS due to limited studies reporting both outcomes [24]. Therefore, through this meta-analysis we aim to (1) identify studies that included an FMS intervention in pre-school (aged 3–5 years) and/or primary school-aged children (5–12 years), with FMS and PA as outcome measures; and (2) determine whether a relationship exists between change in FMS and change in PA levels in these age groups.

2 Methods

2.1 Protocol and Registration

This meta-analysis followed the PRISMA Statement Checklist and was registered with Prospero on 7 July, 2016 (CRD42016042488) as per the 2015 PRISMA Statement [25].

2.2 Search Strategy

An electronic search of Embase, PubMed, Science Direct, Web of Science, SPORTDiscus, Proquest Social Science, Scopus, and Physiotherapy Evidence Database (PEDro) databases was performed on 20 July, 2017. No timeline restrictions were included in the database search. In addition, bibliographies of all eligible original papers and reviews were manually searched. Search terms included 'fundamental motor skills', 'gross motor skills', 'locomotor skills', 'object* skills', 'physical activity', 'children'. The search terms and results returned for each database are shown in Electronic Supplementary Material (ESM) Table S1.

2.3 Study Selection

Studies were included in this meta-analysis if they were a controlled trial that implemented an FMS intervention and quantitatively measured PA levels and FMS in healthy children aged 3–12 years. Papers were excluded if participants had an intellectual or developmental delay, or a chronic disease/disability. Studies that were not written in English and for which a translator was not available to translate the manuscript were also excluded.

Duplicates were removed, and studies were examined by title and abstract by one author. Studies that met the above inclusion criteria were then examined separately by full text in duplicate (AE and NvD), with a third researcher (BP) resolving any conflicts.

Included studies were categorised into two groups: (1) teacher-led interventions (TL) and (2) teacher-educated interventions (TE). A study was placed in the TL category if the children were instructed directly by a person who specialised in the delivery of FMS training. An FMS specialist was defined as someone who has had tertiary training in FMS delivery (e.g. physical education teacher, exercise physiologist or physiotherapist). Studies were placed in the TE category if the staff of the childcare centre or school were only provided with educational material on FMS and PA, and then delivered training to the children based on this material. To be in the TE category, childcare/school teachers delivered FMS training to the children. An FMS specialist did not work directly with the children. Studies were also categorised by age; the two age groups were preschool age (3–5 years old) or school age (6–12).

2.4 Data Extraction and Risk of Bias

Data were extracted independently by one researcher (AE). Authors were contacted for missing data where possible. Where not enough data could be extracted, and authors did not reply to initial contact, papers were excluded from final

quantitative analysis but remained in the qualitative analysis.

In addition to clinical and statistical heterogeneity, further risk of bias of all eligible papers was determined using the PEDro scale [26]. As per PEDro guidelines, a point is awarded if each of the ten criteria is clearly satisfied; a higher score may indicate a higher quality trial, depending on PEDro criteria met within the individual studies. Papers were screened for quality by two authors (AE and CB), with any disagreements being resolved by a third researcher (BP). A qualitative assessment was then completed based on the individual criteria met (e.g. randomisation, concealed allocation, blinded assessors and intention-to-treat analysis all indicated higher quality trial).

2.5 Data Synthesis and Analysis

Outcome measures extracted included total objectively measured FMS proficiency, LS proficiency, OS proficiency, total PA levels (objective and subjective), moderate to vigorous physical activity (MVPA) levels and time spent in SB. The standardised mean difference (SMD) for each outcome was calculated ($\text{SMD} = \text{post-mean} - \text{pre-mean}$). Where studies reported median, standard error, range or interquartile range, and sample size exceeded 25, median was substituted for mean, and other measures converted to standard deviation (SD) as per Hozo et al. [27].

Meta-analyses were completed for each outcome measure for continuous data using the change in mean or mean difference (MD), and SD. Whilst it is recognised practice to use only post-intervention data for meta-analysis, this method assumes that random allocation of participants always creates groups that are equal at baseline in terms of age and skill level, etc. MD was calculated by subtracting baseline from post-intervention values. Change in SD of post-intervention outcomes was calculated using RevMan 5.3 (Cochrane, London, UK). Data required for the meta-analysis was (1) 95% confidence interval (CI) data for pre-post intervention change for each group or, when this was unattainable, (2) actual p values for pre-post intervention change for each group or, if only the level of statistical significance was available, (3) default p values were used (e.g. $p < 0.05$ becomes $p = 0.049$, $p < 0.01$ becomes $p = 0.0099$, and $p = \text{not significant}$ becomes $p = 0.05$). A random effects inverse variance was used with the effects measure of SMD to allow for comparison of the same outcomes that were collected using different methods; for example, different tools used to assess FMS. Significance was set at $p < 0.05$ and confidence intervals at 95%; figures were produced using RevMan 5.3. For correlations, SMD was used. Correlations were performed in IBM SPSS Statistics 23 (IBM, Armonk, NY, USA). Sub-analyses were run to examine the difference between TE and TL

interventions as well as the role that age group, frequency, session duration and intervention length played on the outcome measures.

3 Results

Results of the initial database search yielded 25,242 results. The results from each database search are presented in ESM Table S1. Nineteen trials met the inclusion criteria, five were excluded due to a lack of reported data, leaving 14 trials included in the final quantitative analysis. The PRISMA flow diagram is shown in Fig. 1.

3.1 Risk of Bias

An assessment of the quality of studies found that common areas where most trials failed to meet the criteria were in the blinding of subjects, therapists and assessors. However, the authors acknowledge that it is difficult to blind subjects in a trial investigating the effect of an exercise intervention. The age of the children may play a role here, however, in that pre-schoolers would not necessarily understand that they were undergoing a skill building intervention. The importance of blinding assessors, however, cannot be understated, and may play a role in any bias results. Only three papers reported that assessors were blinded to treatment allocation [28]. Forty-two percent ($n = 8$) [28] of the studies scored a high-quality score (7/10 or higher); 58% ($n = 11$) [28] of studies concealed allocation of participants

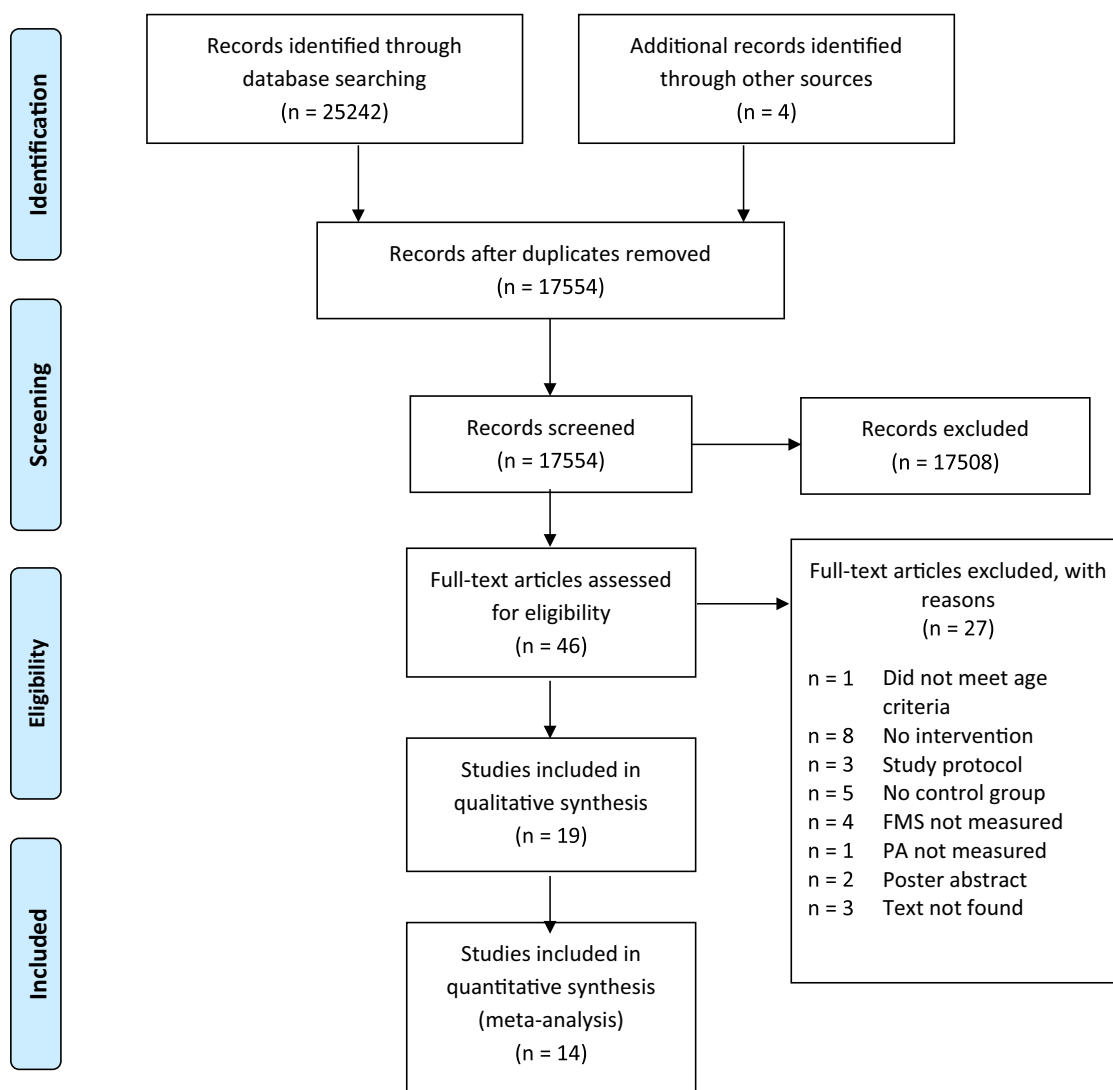


Fig. 1 PRISMA flow chart of search results and papers identified for inclusion. *FMS* fundamental motor skills, *PA* physical activity

to intervention or control group; 16% ($n = 3$) [28] of studies blinded the assessors to which group the participants were in; 74% ($n = 14$) [28, 29, 31, 39] of studies analysed participants as intention to treat. The full PEDro results are outlined in ESM Table S2.

3.2 Participants

Of the 18 trials that met the inclusion criteria, a total of 6014 children (50.75% male) were studied, with 2549 completing some form of FMS intervention. Participants had a mean age of 6.23 ± 2.63 years (range 3.35–10.66); mean height, reported in four papers [31, 36, 37, 40], was 101.6 ± 4.3 cm; mean weight, reported in six papers [31, 33, 36, 37, 40, 44], was 22.0 ± 11.8 kg; and mean body mass index (BMI) ($n = 8$) [30, 31, 33, 34, 36–38, 40] was 17.6 ± 2.8 kg/m².

3.3 Intervention Characteristics

An outline of the intervention characteristics of eligible papers is presented in Table 1. Of the 14 studies included in the quantitative analysis, ten were classified as TL [26, 29, 30, 32, 36–38, 40, 44], and the remaining four as TE [29, 31, 37, 41]. On average, TE interventions ran for 25 ± 14 weeks, had 3 ± 2 sessions per week and each session ran for 39 ± 23 min. TL interventions ran for 43 ± 23 weeks. Due to the nature of the TL studies, there were no descriptors of frequency or time. Ten of the 14 studies were on preschool children [28, 30–32, 36–38, 40, 41, 44] and the remaining four on school-aged children [29, 33, 35]. On average, preschool interventions ran for 28 ± 11 weeks, had 4 ± 1 sessions per week and each session ran for 30 ± 14 min. School-aged interventions ran for 20 ± 22 weeks and had 1 ± 1 sessions per week lasting for 60 ± 30 min. Overall, there were insufficient studies of school-aged children to allow a quantitative analysis.

3.4 Fundamental Motor Skills

When all interventions that recorded total FMS ($n = 11$) [28–33, 36–38, 41, 44] were pooled, the meta-analysis indicated a small, significant improvement in overall FMS (SMD = 0.26 [95% CI 0.14–0.38], $p < 0.0001$) with moderate heterogeneity ($I^2 = 56\%$ and $\text{Chi}^2 p = 0.01$), see ESM Fig. S1. Analysis of TL interventions only ($n = 7$) [28, 30, 32, 33, 36, 38, 44] showed a small significant increase (SMD = 0.28 [95% CI 0.14–0.43]; $p = 0.0001$) but with moderate, significant heterogeneity ($I^2 = 52\%$ and $\text{Chi}^2 p = 0.05$). TE interventions ($n = 4$) [29, 31, 37, 41] showed a small, insignificant improvement (SMD = 0.23

[95% CI – 0.02 to 0.49]; $p = 0.07$) with moderate, significant heterogeneity ($I^2 = 68\%$ and $\text{Chi}^2 p = 0.02$).

When analysed by age, preschool-aged children ($n = 9$) [28, 30–32, 36–38, 41, 44] had a small, significant improvement (SMD = 0.19 [95% CI 0.07–0.54]; $p = 0.001$) with insignificant heterogeneity ($I^2 = 43\%$ and $\text{Chi}^2 p = 0.07$). Analysis of school-age children was unable to be completed due to only two studies recording total FMS. Further sub-analysis of TL interventions with three or more sessions per week ($n = 6$) [28, 30, 32, 36, 38, 44] revealed a similar small, significant improvement (SMD = 0.23 [95% CI 0.11–0.36]; $p = 0.0002$) with heterogeneity lowered further ($I^2 = 32\%$ and $\text{Chi}^2 p = 0.2$), see ESM Fig. S2.

Balance was measured in only one study [39] with no significant improvement seen.

3.5 Locomotor Skills

When all TE and TL interventions that recorded LS ($n = 4$) [29, 31, 33, 40] were pooled, there was a small, significant improvement (SMD = 0.36 [95% CI 0.20–0.52]; $p < 0.0001$) and the analysis revealed homogeneity with $I^2 = 0\%$ and $\text{Chi}^2 p = 0.45$, see ESM Fig. S3. Further sub-analysis was unable to be completed due to the small number of studies measuring LS.

3.6 Object Control Skills

When all TE and TL interventions that recorded OS ($n = 4$) [29, 31, 33, 45] were pooled, the meta-analysis indicated a small, significant improvement (SMD = 0.30 [95% CI 0.08–0.52]; $p = 0.007$) and the analysis revealed a small, insignificant heterogeneity with $I^2 = 44\%$ and $\text{Chi}^2 p = 0.15$, see ESM Fig. S4. Further sub-analysis was unable to be completed due to the small number of studies measuring OS.

3.7 Physical Activity Levels

When all interventions that recorded total PA ($n = 10$) [28–31, 33, 37, 38, 41, 44, 45] were pooled, the meta-analysis indicated a small, significant increase in the amount of PA performed (SMD = 0.27 [95% CI 0.11–0.44]; $p = 0.002$); however, heterogeneity was substantial and significant ($I^2 = 64\%$ and $\text{Chi}^2 p = 0.003$), see ESM Fig. S5. Analysis of TL interventions only ($n = 6$) [28, 30, 33, 38, 44, 45] showed a trivial significant increase (SMD = 0.18 [95% CI 0.02–0.34]; $p = 0.036$); however, heterogeneity was no longer significant ($I^2 = 40\%$ and $\text{Chi}^2 p = 0.14$). TE interventions ($n = 4$) [29, 31, 37, 41] showed a small significant improvement (SMD = 0.46 [95% CI 0.07–0.86]; $p = 0.02$); however, heterogeneity was

Table 1 Descriptions for studies included in the qualitative synthesis

Study	Age group	Intervention type	Control condition	Additional activities	Frequency (days/week)	Time (mins)	Intervention length	FMS measurement tool	PA measurement tool (brand)	Length of PA measurement
Adamo et al. [31]	Preschool	TE	Regular childcare curriculum		NA	NA	6 months	TGMD-2	Accelerometer (Actical)	7 consecutive days
Alhassan et al. [40]	Preschool	TL	Unstructured free play		5	30	6 months	TGMD-2	Accelerometer (Actigraph)	Waking hours for 7 consecutive days
Bellows et al. [36]	Preschool	TL		12-week nutrition programme	4	15–20	18 weeks	PDMS-2	Pedometer (Walk4Life)	Waking hours for 6 days (4 weekdays, 2 weekend days)
Bonvin et al. [37]	Preschool	TE	Regular childcare curriculum				10 months	ZNA	Accelerometer (Actigraph)	1 day (considered valid if at least 3 hours)
Boyle-Holmes et al. [42]	School	TL	Regular school physical education curriculum		2	30	1 academic year	Based on the Michigan Physical Education Content Standards Forehand strike Lift and carry leap	SAPAC	1 school day
Bryant et al. [43]	School	TL	Regular school physical education curriculum		1	45	6 weeks	POC	Pedometer (Yamax)	4 days (2 weekdays, two weekend days)
Cliff et al. [33]	School	TL	Dietary modification programme	Dietary modification program and 'home challenge' activities	1 (for first 10 weeks)	120 (at least 90 min of PA)	26 weeks (10 weeks face to face, the remaining time as a maintenance phase)	TGMD-2	Accelerometer (Actigraph)	Waking hours for 8 consecutive days, excluding aquatic activities

Table 1 continued

Study	Age group	Intervention type	Control condition	Additional activities	Frequency (days/week)	Time (mins)	Intervention length	FMS measurement tool	PA measurement tool (brand)	Length of PA measurement
Cohen et al. [29]	School	TE	Regular school curriculum		NA	NA	12 months	TGMD-2	Accelerometer (Actigraph)	Waking hours for 7 consecutive days, excluding aquatic activities
Froehlich Chow et al. [41]	Preschool	TE	Regular childcare curriculum		NA	NA	48 weeks	TGMD-2	Accelerometer (Actigraph)	7 consecutive days
Grillich et al. [34]	School	TE	Regular school curriculum	Two 8-hour workshops focusing on PA and teaching practices for teachers	NA	NA	1.5 academic years	Subtests from GMT and KiKo	PAQ-C	7-day PA recall
Jones et al. [38]	Preschool	TL	Regular childcare curriculum including designated free play time	Unstructured activities in the afternoon where skill-specific equipment is provided	3	20	20 weeks	TGMD-2	Accelerometer (Actigraph)	2 consecutive days whilst at childcare centre
Jones et al. [28]	Preschool	TL	Regular childcare curriculum including designated free play time	Unstructured activities in the afternoon where skill-specific equipment is provided	3	20	6 months	TGMD-2	Accelerometer (Actigraph)	2 consecutive days whilst at childcare centre
Miller et al. [35]	School	TL	Games and sport strand from the NSW BOS		1	60	6 weeks	TGMD-2	SOFIT	During intervention class (4 randomly selected students)
Nathan et al. [45]	School	TL	Usual practice		2	30	10	Object control section of TGMD-3	Pedometer (Yamax)	5 consecutive school days
Reilly et al. [30]	Preschool	TL	Regular childcare curriculum	Home-based health education aimed at increasing PA	3	30	12 months (24 weeks of lessons)	Movement assessment battery	Accelerometer (Manufacturing Technology)	Six consecutive days

Table 1 continued

Study	Age group	Intervention type	Control condition	Additional activities	Frequency (days/week)	Time (mins)	Intervention length	FMS measurement tool	PA measurement tool (brand)	Length of PA measurement
Roth et al. [32]	Preschool	TL	Regular childcare curriculum	PA homework cards once or twice per week. Seasonal letters with games over the holidays	5	30	1 academic preschool year	Obstacle course Standing on one foot (modified) Standing long jump Jumping to-and-fro sideways	Accelerometry	At least 7 hours per day for 3 weekdays and a weekend
Salmon et al. [51]	School	TE	Behavioural modification programme	Behavioural modification programme	19 sessions throughout the study	40–50	3 school terms	‘Established protocol’ Overhand throw Two-handed strike Kick Dodge Sprint run Vertical jump	Accelerometer (Manufacturing Technology)	8 consecutive unless swimming or bathing
van Beurden et al. [39]	School	TE	Regular school curriculum		NA	NA	1 year	Protocol written in accordance with NSW DET resources Static balance Sprint run Vertical jump Kick Hop Atch Overhand throw Side gallop	SOFIT	12 20-second periods during physical education lessons

Table 1 continued

Study	Age group	Intervention type	Control condition	Additional activities	Frequency (days/week)	Time (mins)	Intervention length	FMS measurement tool	PA measurement tool (brand)	Length of PA measurement
Yin et al. [44]	Preschool	TL	Regular childcare curriculum	Age-appropriate CDs and DVDs that encouraged movement and dance (15–20 min)	5	30–45	18 weeks	LAP-3	Pedometers	3 days whilst children were in centre

Preschool = age 3–5 years; School = age 5–12 years

FMS fundamental motor skills, GMT German Motoric Test, KiKo Children's Coordination Test, LAP-3 Learning Achievement Profile Version 3, NA not applicable, NSW BOS New South Wales Board of Studies, NSW DET New South Wales Department of Education and Training, PA physical activity, PAQ-C Physical Activity Questionnaire for Older Children, PDMS-2 Peabody Developmental Motor Scales, 2nd Edition, POC Process Oriented Checklist, SAPAC The Self-Administered Physical Activity Checklist, SOFIT System for Observing Fitness Instruction Time, TE teacher educated, TGMD-2 Test of Gross Motor Development 2nd Edition, TGMD-3 Test of Gross Motor Development 3rd Edition, TL teacher led, ZNA Zurich Neuromotor Assessment

considerable and significant ($I^2 = 81\%$ and $\text{Chi}^2 p = 0.001$). Preschool-aged children ($n = 7$) [28, 30, 31, 37, 38, 41, 44] had a small significant improvement in PA (SMD = 0.32 [95% CI 0.09–0.54]; $p = 0.006$); however, heterogeneity was substantial and significant ($I^2 = 76\%$ and $\text{Chi}^2 p = 0.0004$). School-age children ($n = 3$) [29, 33, 45] had a small significant improvement (SMD = 0.23 [95% CI 0.03–0.42]; $p = 0.02$) with perfect homogeneity ($I^2 = 0\%$ and $\text{Chi}^2 p = 1.00$). Further sub-analysis of TL interventions with three or more sessions per week ($n = 4$) [28, 30, 38, 44] revealed a trivial non-significant increase in PA (SMD = 0.18 [95% CI – 0.05 to 0.41]; $p = 0.13$), with substantial heterogeneity ($I^2 = 60\%$ and $\text{Chi}^2 p = 0.06$), see ESM Fig. S6.

3.8 Moderate–Vigorous Physical Activity

When all interventions that recorded MVPA ($n = 10$) [28–31, 33, 35, 37, 38, 40, 41] were pooled, the meta-analysis indicated a small, significant increase in the amount of MVPA children were completing (SMD = 0.22 [95% CI 0.07–0.38]; $p = 0.005$), although heterogeneity was moderate and significant with $I^2 = 57\%$ and $\text{Chi}^2 p = 0.01$, see ESM Fig. S7.

TE interventions ($n = 4$) [29, 31, 37, 41] showed a small significant improvement (SMD = 0.39 [95% CI 0.02–0.76]; $p = 0.04$); however, heterogeneity was significant ($I^2 = 79\%$ and $\text{Chi}^2 p = 0.002$). Preschool-aged children ($n = 7$) [28, 30, 31, 37, 38, 40, 41] had a small significant increase (SMD = 0.21 [95% CI 0.01–0.40]; $p = 0.03$); however, heterogeneity was substantial ($I^2 = 63\%$ and $\text{Chi}^2 p = 0.01$). Analysis of school-age children ($n = 3$) [29, 33, 35] revealed a small significant increase (SMD = 0.29 [95% CI 0.08–0.51]; $p = 0.007$) with homogeneity of results ($I^2 = 0\%$ and $\text{Chi}^2 p = 0.37$). There were no significant results for TL interventions.

3.9 Sedentary Behaviours

When all interventions that recorded SB ($n = 6$) [28, 30, 31, 38, 40, 41] were pooled, the meta-analysis indicated a small, insignificant decrease in the amount of time children spent sedentary (SMD = – 0.36 [95% CI – 0.71 to – 0.01]; $p = 0.05$); however, heterogeneity was considerable and significant with $I^2 = 82\%$ and $\text{Chi}^2 p < 0.0001$, see ESM Fig. S8. All interventions that recorded SB were performed in preschool-aged children and it was therefore unnecessary to do this sub-analysis.

3.10 Correlations

There was a strong, significant correlation between PA and MVPA ($n = 8$) [28–31, 33, 37, 38, 41] ($r = 0.87$;

$p = 0.005$) and strong, significant negative correlations between MVPA and SB ($n = 6$) [28, 30, 31, 38, 40, 41] ($r = -0.920$; $p = 0.009$).

Preschool-aged children showed similar results to the pooled studies, with a strong, significant correlation between PA and MVPA ($n = 6$) [28, 30, 31, 37, 38, 41] ($r = 0.958$; $p = 0.003$). The relationship between MVPA and SB was the same as for the all-intervention data as all the studies that recorded these measures were conducted in pre-schoolers.

In TL interventions, there was a significant, almost perfect negative relationship between MVPA and SB ($n = 4$) [28, 30, 38, 40] ($r = -0.969$; $p = 0.031$).

4 Discussion

The purpose of this meta-analysis was to investigate the relationship between FMS and PA in preschoolers and primary-school-aged children following an FMS intervention. Thirteen papers examining FMS interventions were included in this analysis, nine TL and four TE. When all papers were pooled, a significant improvement was seen in overall FMS, LS, OS, PA, MVPA and SB. This suggests that significant increases in FMS proficiency and PA levels can be achieved through an intervention, consistent with a previous meta-analysis [24]. However, only LS and OS had insignificant heterogeneity, indicating the vast differences in study results for other outcomes.

Sub-analyses revealed that when the specifics of a study (intervention type, age group, intervention length, sessions/week) were explored, significant results could be attained with homogeneity. This was evident with the sub-analysis of TL interventions, with three or more sessions per week significantly increasing FMS proficiency. PA and MVPA were also increased slightly, although the results were insignificant in the small number of studies. Coincidentally, all the studies that fit into this sub-analysis ($n = 7$) [28, 30, 32, 36, 38, 40, 44] were performed in preschool-aged children, raising the question as to whether these studies would be equally effective in school-aged children.

When interpreting the correlations between outcomes, some interesting findings emerged. The differences between intervention designs became clear with no relationships evident between FMS and measures of PA when all studies were pooled together. When all interventions were grouped together, a significant, strong relationship between PA and MVPA ($r = 0.870$) was observed, indicating that children who performed more PA did so at a higher intensity. When only preschool-aged children were considered, the link between PA and MVPA became even stronger ($r = 0.958$), indicating that pre-schoolers, when physically active, spent more time at the higher intensity

MVPA than school-aged children. This is important as children's PA guidelines are based on the amount of time they spend participating in MVPA [46], not lower intensity light PA. The relationship between MVPA and SB ($r = -0.920$, $p = 0.009$) may indicate that children who are attaining the higher intensities of PA are not simply active for a short period, or bout of sport, but are rather maintaining PA throughout the day. With regard to the interventions that had the most success at improving FMS, TL interventions consisting of three or more sessions/week showed a significant, strong negative relationship between MVPA and SB ($r = -0.969$, $p = 0.031$), indicating that such interventions produced promising results, increasing MVPA and reducing SB.

Based on the results of this meta-analysis, interventions are most effective at increasing FMS proficiency when targeted at preschool children using TL interventions at least three sessions per week for ≤ 6 months. These interventions may also increase PA and MVPA and decrease SB; however, further studies need to be completed to quantify this effect.

4.1 Strengths of this Review and Meta-analysis

This systematic review and meta-analysis used a sensitive search strategy to ensure relevant studies were not missed. In addition, rigorous review methodology, including independent, duplicate review of selected studies, ensured most studies were captured. The PEDro scale, a reliable and validated tool [26], was used to assess the quality and risk bias of included studies, and a thorough qualitative analysis was completed prior to the quantitative synthesis of the studies. Furthermore, analysis of sub-groups was performed on outcomes where there was substantial heterogeneity to attempt to explain possible causes.

4.2 Limitations and Recommendations for Future Research

The main limitation of this analysis was that only a small number of trials assessed FMS and PA in children. A number of studies have investigated a cross-sectional relationship between FMS and PA in pre-schoolers [47] and school-aged children [48, 49], but the number that have measured both these outcomes following an FMS intervention is low, therefore limiting the results of this meta-analysis.

Possible bias within the studies was another limitation of the analysis. It is difficult to blind therapists and participants in a PA intervention, although due to their age, preschool children may be 'blinded'. However, the importance of blinding assessors, only achieved by three studies [28–30], cannot be understated and may have led to

a bias in the outcome results, especially in those studies with assessments of a subjective nature.

A recent systematic review exploring the implementation and assessment of school-based PA interventions found that there is ‘substantial variability’ in how interventions are implemented and health outcomes are assessed [50]. Along with the diverse range of intervention characteristics found in this meta-analysis (Table 1), the variability of assessment of outcomes and intervention implementation may have also been a factor in the significant level of heterogeneity identified in the studies. However, this heterogeneity reduced when studies with sessions conducted by an FMS specialist (TL) three or more times a week for approximately 6 months were pooled in the analysis. This indicates that programmes run at least three times per week by an FMS specialist have more homogeneous results and can significantly improve FMS. Unfortunately, due to the variation of prescriptions, we were unable to identify any further prescriptive recommendations. More study is required on the intensity and type of FMS exercises that should be implemented. It was noted that balance was not routinely measured in studies included in this review. However, FMS assessment tools (e.g. Test of Gross Motor Development, 3rd edition) [16] are adding it as an outcome. Future FMS trials should consider implementing balance training. Sub-analysis was required to achieve significant results with non-significant heterogeneity. This sub-analysis then reduced the significance of relationships between FMS and measures of PA. Although relationships were found, a lack of studies meant it was difficult to determine significance. This is seen in the relationships of TL studies with three or more sessions per week.

The findings of this analysis have significant implications for future studies, preschools and parents, as they indicate that children need to practise their FMS skills regularly (≥ 3 times per week) to achieve a significant improvement in FMS, and potentially PA levels. Our analysis also indicates that the best way for children to learn these skills may be by being explicitly taught by a teacher, rather than having the skills included in their everyday pre-school activities. These results are consistent with those of a previous meta-analysis [24].

5 Conclusions

TL interventions conducted three or more times a week were associated with significant increases in FMS, and trends towards increasing PA and MVPA levels in pre-schoolers. The effects, however, in older children are unknown. TL studies in pre-schoolers have strong, significant relationships with increases in PA and MVPA;

however, only TL studies including three or more sessions per week showed a strong relationship between increased FMS proficiency and increasing MVPA levels. Results indicate that training pre-schoolers at least three times a week in FMS can improve proficiency as well as increase intensity of PA, and reduce SB, possibly helping to reduce the burden of childhood obesity and its associated health risks.

Compliance with Ethical Standards

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