The effectiveness of fundamental movement skill interventions on moderate to vigorous physical activity levels in five to eleven-year-old children: A systematic review and meta-analysis

**Running title:** Effect of FMS interventions on MVPA in five to eleven year old children

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Abstract

Background: Fundamental movement skill (FMS) competence is associated with physical activity during childhood, with higher FMS competence associated with higher physical activity levels. However, the effectiveness of FMS interventions in primary school aged children is not fully understood.

Objective: The purpose of this study is to evaluate the effectiveness of FMS interventions at improving daily levels of moderate to vigorous physical activity (MVPA) in 5 to 11-year-old children.

Methods: Systematic searches were completed in eight electronic databases (MEDLINE, CINAHL, PubMed, Web of Science, SportDiscus, EMBASE, ERIC, Scopus). Studies were included if they were randomised or non-randomised controlled trials that implemented a physical activity intervention with a FMS component, in 5 to 11-year-old children and included objectively measured daily levels of MVPA. Methodological quality was assessed using the Cochrane’s risk of bias tools for randomised and non-randomised controlled trials. Random effects meta-analysis was performed to determine the pooled intervention effect (mean difference) on minutes spent in MVPA with meta-regression for the use an operationalised definition of FMS, in line with Logan et al.’s criteria.

Results: A total of 19 studies were identified for review and 14 studies eligible for meta-analysis. The pooled intervention effect was 4.3 minutes (95%CI: -0.03 to 8.8) of MVPA per day. The percentage of future studies likely to find an effect greater than the minimal clinically important difference was 47% (95%CI: 22 to 70). Studies that attempted to conceptualise and define FMS by combining at least one of Logan et al.’s operational definitions with a measure of FMS had a positive effect on daily MVPA (13.3 min/day; 95%CI: 8.0 to 18.6; R² =0.89). Meta-regression for the three levels of Logan et al.’s criteria showed a linear increase in MVPA with studies using all three criteria experiencing the largest additive effect (15.7 min/day: 95%CI: 8.9 to 22.6; R² =0.89).

Conclusions: Fundamental movement skill interventions have the potential to increase daily levels of MVPA in 5 to 11-year-old children. However, future studies should concentrate on establishing an accurate conceptualisation of FMS and how FMS will be integrated within their intervention to further increase physical activity levels.

Trial registration: Prospero registration number: CRD42017058718
**Key points:** Fundamental movement skill (FMS) interventions have the potential to increase daily levels of MVPA beyond the levels required to reverse the current rate of MVPA decline in childhood.

The pooled intervention effect of 4.3 minutes (95%CI: -0.03 to 8.8) of MVPA per day compared to controls is greater than the defined minimal clinically important difference (MCID) of 3.6 minutes of MVPA in this study.

There is substantial heterogeneity in FMS interventions. Studies which applied a definition and conceptualisation of FMS, in line with Logan et al.’s criteria had a positive effect on daily MVPA compared to studies that did not meet the established criteria.
1. Introduction

Higher physical activity levels are associated with physiological, psychological and psychosocial health among children [1, 2]. In particular, an increase in moderate to vigorous physical activity (MVPA) has beneficial effects on cardio-metabolic risk factors in children, independent of other risk factors (i.e. adiposity) [3], which led the UK Chief Medical Officers (4) and World Health Organisation (5) to recommend that children between the ages of 5 to 18 years should engage in (MVPA) for an average of at least 60 minutes per day across the week. However, many children and adolescents do not meet MVPA recommendations [6, 7, 8]. Furthermore, the volume of physical activity (total and MVPA) begins to decline by the age of 7 years [2, 9, 10] or in some cases earlier [11].

An important contributor to the amount of physical activity children take part in is fundamental movement skill (FMS) competence. A higher level of FMS competence attenuates the decline in physical activity throughout childhood [12] and is important for physical development and physical activity across the lifespan [13]. FMS consist of three main constructs; locomotor (run, hop, jump, slide, gallop, leap); object control (strike, dribble, kick, throw, underarm roll, catch); and balance/stability skills (non-locomotor skills such as body rolling, bending and twisting) [14]. Stodden et al. [15] suggested that physical activity and motor competence have a reciprocal relationship during the early years of childhood. This suggests a higher level of physical activity engagement drives FMS development, whilst higher FMS competence leads to more opportunities to be physically active. Development of FMS during early childhood is thought to be critical to physical activity participation from early years throughout primary school years [16]. Early development of FMS forms a skill base that acts as a foundation to master the more complex physical activities needed throughout the life course [17-19].

Systematic reviews highlight the positive associations between FMS and physical activity and health related fitness in early years children, primary school children and adolescents [20-25]. Lubans et al. [23] conducted a systematic review including 19 studies (15 cross sectional, 2
longitudinal, 2 experimental) exploring the association between FMS and physical activity across childhood (3 to 18 years old). From the 15 cross-sectional studies included, Lubans et al. [23] identified positive associations between FMS competency and physical activity and cardiorespiratory fitness in children and adolescents. However, data extracted from the two longitudinal studies provided less conclusive evidence for a FMS and physical activity relationship. A meta-analysis was not possible due to an inadequate number of longitudinal and experimental studies reporting these variables.

Tompsett, Sanders, Taylor and Cobley [26] conducted a systematic review to explore and identify FMS intervention characteristics that could provide an area of increased focus that would be beneficial on physiological, psychological, and behavioural outcomes in children and adolescents. Following a review of 29 studies, the authors concluded that FMS interventions that encourage psychological autonomy were the most efficacious on FMS and physical activity outcomes. Tompsett et al. [26] highlighted that 93% of included studies reported positive influences of FMS interventions on FMS outcomes. However, the findings of this review are limited given the inclusion of a broad age range of children (5 to 18 years old), studies with a focus on overweight/obese children and children with developmental delay/disorders; each of which (age, weight status, development delay) has strong moderating effects on FMS proficiency [27]. Moreover, their selection criteria was inclusive of single group studies (i.e. no control group) which significantly denigrates the effectiveness of such interventions beyond what could be expected from no intervention (i.e., continuing with the usual PE curriculum).

A more recent systematic review identified 18 articles that investigated the effectiveness of FMS interventions in 3 to 12-year-old children [25] with a number of meta-analysis conducted for the various outcome measures identified by the authors. Eleven articles contributed data for a meta-analysis of FMS as an outcome with the authors identifying a small, significant improvement in overall FMS (SMD = 0.26; 95%CI 0.14 to 0.38; p = <0.0001) [21]. Furthermore, of the studies that measured MVPA as an outcome (n = 10), meta-analysis of the pooled data
showed a small significant effect in favour of the intervention (SMD = 0.22; 95%CI 0.07 to
0.38; p = 0.005). These findings are important as it is the first pooled quantitative analysis of
FMS and physical activity outcomes from FMS interventions. However, the number of studies
identified by Engel et al. [25], as measuring FMS in primary school children were insufficient
for meta-analysis (n=2) and the MVPA effects presented by the authors are inclusive of both
preschool and primary school age studies. Furthermore, whilst previous systematic reviews
examined the cross-sectional or longitudinal association between FMS and physical activity
[20-24]. Only a few have examined the determinants [26] or effectiveness of FMS interventions
[25]. Therefore, the effectiveness and determinants of FMS interventions in 5 to 11 year old
(primary school) children remain unknown.

Despite the growing popularity to include FMS in childhood physical activity interventions [24],
the FMS components of the interventions are not always clear. The duration, frequency and
intensity of the individual sessions of an intervention can impact the effectiveness of the
intervention [28]. Likewise, there are additional factors which could affect the magnitude of the
effectiveness of FMS interventions [28-30], which until now have not been fully addressed.
For example, it is widely accepted that FMS do not naturally develop over time and require
teaching, training, practice and modelling, which are all important to the development of FMS
due to their ontogenetic characteristics [15, 19, 27, 31]. It is also expected that interventions
which include FMS will naturally increase physical activity levels. However, this concept
ignores the complex nature of movement skill development; described as a continuous change
in movement behaviour throughout the life cycle through the interactions of tasks, individual
biology and environmental conditions [14].

Finally, Logan et al.'s [32] systematic review of FMS terminology highlighted the importance
for researchers to provide a high-quality, operational definition for the construct of FMS
development to improve the consistency and clarity of the context in which FMS is used. Many
of the studies included in the review (n=30) did not report any operational definition of FMS
leading the authors to provide an operational definition for researchers with an interest in
movement skills to use in future reporting of FMS research. Although it is acknowledged that
there are many interpretations of FMS that are likely domain specific (e.g., public health versus
athlete development) studies with a focus on FMS could improve the clarity by including the
following three criteria, in line with Logan et al.’s [32] definition; 1) inclusion of a statement that
suggests FMS are the “building blocks” (or similar terminology) of more advanced, complex
movements required to participate in games, sports or other context specific physical activity;
2) inclusion of a statement that provides specific categories of skills that compose FMS such
as object control, locomotor, or stability skills; and 3) provide at least one specific example of
FMS (i.e. running, jumping, throwing etc.) [32].

There has been a rise in the development of interventions utilising FMS with the primary aim
of increasing physical activity levels of children [33-38]. However, to our knowledge a thorough
qualitative synthesis and meta-analysis of the findings on the effect of FMS interventions on
daily levels of MVPA in primary school aged children is lacking. The aim of this review is to
synthesize and meta-analyse the effectiveness of FMS interventions at improving daily levels
of MVPA in 5 to 11 year olds. The secondary aim is to explore if specific types of delivery (e.g.
instructor type, single or multicomponent) and a clear conceptualisation and definition of FMS
offered in the intervention would lead to a further positive effect on physical activity outcomes.

2. Methods

This systematic review and meta-analysis was registered with Prospero in May 2017
(CRD42017058718) and follows the Preferred Reporting Items for Systematic Reviews and
Meta-Analysis (PRISMA) statement [39].

2.1 Study inclusion and exclusion criteria

Articles were eligible if they were a randomised or non-randomised controlled trial that
delivered a physical activity intervention in typically developing 5 to 11 year old children, with
a FMS component (identified by use of FMS terminology or by explicit FMS activities in the
methods sections of reviewed studies) within a school/community setting. Furthermore,
studies needed to have included an objective, validated measure of MVPA (e.g., accelerometer).

Studies were excluded if they specified a focus on a population with a health condition (e.g., overweight/obese, developmental coordination disorder, Down syndrome, other neurological/movement disorders) which has been previous identified to have negative associations with FMS competence and physical activity levels [27, 40-43]. Furthermore, studies were excluded if they had a cross-sectional or longitudinal methodology, and if the articles were not original research (i.e., reviews, surveys, opinion pieces, book chapter).

Finally, texts that were not available in English language were excluded. A full description of inclusion and exclusion criteria are presented in Table 1.

Table 1. Exclusion criteria for study selection with respective codes and descriptions

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Duplicate</td>
<td>Duplicate result returned from another database</td>
</tr>
<tr>
<td>D (d)</td>
<td>Duplicate: same database</td>
<td>Duplicate result returned from the same database</td>
</tr>
<tr>
<td>X</td>
<td>Excluded: irrelevant topic</td>
<td>Topic of a different discipline</td>
</tr>
<tr>
<td>E1</td>
<td>Excluded: not original research</td>
<td>Reviews, surveys, opinion pieces, books, periodicals, editorials, non-academic/non-peer-reviewed text (grey literature).</td>
</tr>
<tr>
<td>E2</td>
<td>Excluded: research design</td>
<td>Cross sectional, Longitudinal, no control group or use of alternative treatment (i.e. involving alternative form of physical activity)</td>
</tr>
<tr>
<td>E3</td>
<td>Excluded: participants &lt;5 and &gt;11 years of age</td>
<td>Preschool/early years or secondary/adolescent/youth. Participants not between age range of 5 and 11 years at baseline</td>
</tr>
<tr>
<td>E4</td>
<td>Excluded: special population</td>
<td>SEN, Overweight/Obese, DCD, Visual impairments, recognised development disorder/disability/illness affecting usual movement/development</td>
</tr>
<tr>
<td>E5</td>
<td>Excluded: No identifiable FMS intervention</td>
<td>No FMS intervention stated by author. No individual construct identified using Gallahue, Ozmun and Goodway (2011). Reviewer unable to identify FMS from methodology.</td>
</tr>
<tr>
<td>E6</td>
<td>Excluded: intervention setting</td>
<td>Either laboratory based or home based intervention</td>
</tr>
<tr>
<td>E7</td>
<td>Excluded: no English FT</td>
<td>Full text not available in English.</td>
</tr>
<tr>
<td>E8</td>
<td>Excluded: did not report a measure of daily level of MVPA</td>
<td>Unable to provide data for comparison between baseline and post intervention/follow up measures. No pre to post intervention measure for MVPA.</td>
</tr>
<tr>
<td>E9</td>
<td>Excluded: No valid/objective measure of MVPA</td>
<td>Did not use a previously validated objective measure for MVPA (i.e. accelerometry).</td>
</tr>
</tbody>
</table>

FT – Full text; SEN – Special educational needs; DCD – Developmental Coordination Disorder; FMS – Fundamental Movement Skills; MVPA – Moderate to vigorous physical activity; TGMD – Test of gross motor development; M-ABC-Movement assessment battery for children; CHAMP’s – Children’s activity and movement in preschool study; PDMS – Peabody developmental motor scale
2.2 Search strategy

Eight electronic databases (MEDLINE, CINAHL, PubMed, Web of Science, SportDiscus, EMBASE, ERIC, and Scopus) were systematically searched. Reference lists of included articles were additionally screened for any relevant articles.

Searches were conducted from inception up to December 2020. The search strategy was built to include all search terms/keywords using the PICO (Population, Intervention, Control, Outcomes) approach for systematic reviews. A pilot search (of titles/abstracts/keywords/full texts) of previously known articles identified keywords used in the search strategy. Keywords/terms associated with "children" (population), "fundamental movement skills" (intervention), "controlled" (Comparator/design) and "physical activity" (outcome) were used to create a Boolean search phrase using the operators 'OR' and 'AND' (e.g. "Child*" OR "Primary School"... AND "Fundamental movement skills" OR "Motor skills"...AND "randomi?ed control* trial"...AND "physical* active*"...). A full search strategy can be seen in supplementary material, Appendix S1, Table S1.

2.3 Study selection and screening strategy

Returned articles from database searches were independently exported into a Microsoft Excel worksheet which identified duplicate articles across databases. Once duplicates were removed, three independent reviewers (MG, AI, LA) screened titles and abstracts from the remaining articles and articles from additional sources, against previously agreed eligibility criteria (Table 1). MG screened all titles and abstracts, whilst AI and LA screened half each. Any disagreements and uncertainty in eligibility were discussed and agreed with a third reviewer (AI or LA) until a consensus was reached. Eligible studies selected from the first screening were retrieved and read in full by three reviewers (MG, AI and LA). Any disagreements during this process were discussed and agreed before continuing. In cases
where agreements were not possible because of lack of information authors were contacted for clarification.

2.4 Data extraction

Three researchers (MG, AI, LA) independently gathered all relevant data using a standard data extraction form (Microsoft Excel, Microsoft, Redmond, USA). Data included participant characteristics (height, weight, % male/female, Body Mass Index, % overweight/obese, Socio-economic status, ethnicity), whether an operational definition of FMS was included in the article [32]; age group, sample size, number of schools and classes used in control and intervention groups; intervention and control group characteristics; study details (design, setting, unit of randomisation, frequency and duration of sessions, intervention duration, time to follow up); FMS measurement tool used and domains measured; physical activity measurement method, monitor details (type, classification of wear time and non-wear time, cut-points used, epoch) and analysis methods. Baseline and outcome data extracted included baseline, post and follow up MVPA in minutes per day (accelerometry), and FMS competence. There was a variation on how authors reported FMS competence as this included raw scores, combined scores (i.e., gross motor quotients) or norm-referenced scores (z-score).

Articles that duplicated data from multiple reports were reviewed again by two researchers (MG and AI) and all available data collated to ensure we had the most complete data set [44]. Any discrepancies at this stage were discussed and agreed by a third reviewer (LA). Authors were contacted in cases where data were presented as median and ranges (in place of mean and Standard Deviation) and where data were unclear or missing [11, 45-50]. In cases when the authors did not respond or were unable to locate the relevant data, the articles were subsequently excluded from the meta-analysis [50]. Graph digitizer software (Digitizelt, Brainschweig, Germany) was used to obtain data from studies where data were only available in figures [46]. Higgins and Green [51] equations were used to convert data to the desired format (e.g., Standard Error to Standard Deviation), for combining groups (e.g., male and
female; Moderate Physical Activity and Vigorous Physical Activity) and for calculating the
effective sample sizes for any clustering effect in cluster trials.

2.5 Quality assessment

The Cochrane risk of bias 2.0 (RoB2.0) [52] and the risk of bias in non-randomised studies of
interventions (ROBINS-I) [53] were used by three independent reviewers (MG, AI, LA) to
evaluate quality of eligible studies. Studies assessed using the RoB2.0 were scored as either
‘low risk’, ‘some concerns’ or ‘high risk’ for each domain; (1) bias arising from the
randomization process; (2) bias due to deviations from intended interventions; (3) bias due to
missing outcome data; (4) bias in measurement of the outcome; (5) bias in selection of the
reported result. Overall study bias was scored using the algorithms provided in the RoB2.0
guidance documents. In brief, a study was judged as ‘low risk’ if the study scored low in all
domains, ‘some concerns’ if the study was judged to raise some concerns in at least one
domain but no high risk judgements, and ‘high risk’ if the study was judged to be either high
in at least one domain or to have some concerns in multiple domains [52].

The studies assessed using the ROBINS-I tool, involved identifying preliminary confounders
and assessing as either ‘low risk’, ‘moderate risk’, ‘serious risk’, or ‘critical risk’ for (1) bias due
to confounding; (2) bias in selection of participants into the study; (3) bias in classification of
interventions; (4) bias due to deviations from intended interventions; (5) bias due to missing
data; (6) bias in measurement of outcomes; (7) bias in selection of the reported result [54].
Overall study bias was judged ‘low risk’ if the study was judged as low for all domains,
‘moderate risk’ if judged to be low or moderate across the domains, ‘serious risk’ if judged
serious in at least one domain and ‘critical risk’ if judged to be critical in at least one domain
[54].

2.6 Data analysis

Comprehensive meta-analysis (CMA) software (Version 3; Biostat, Inc. Englewood, NJ07631,
USA) was used to perform a random effects meta-analysis to determine the pooled
intervention effect (mean difference) on minutes spent in MVPA. Due to the variety of methods of reporting MVPA in the included studies, only studies reporting MVPA in minutes per day were included in the meta-analysis. Studies reporting MVPA using other methods (i.e., percentage time spent in MVPA, counts per minute) are included in the narrative synthesis only. For the meta-analysis uncertainty in the pooled effect was expressed as 95% confidence intervals (CI) with between study heterogeneity (Tau ^2) quantified using DerSimonian and Laird [55] (methods of moments) estimator with Hartung-Knapp t-distribution. Eggers regression coefficient and 95% CI were used to explore potential small study effects.

In the case of substantial between study heterogeneity, categorical meta-regression was completed using the following variables as moderators: 1) ‘If a measure of FMS competence was used with at least one of Logan et al.’s criteria’ [32] (two levels: Yes/No) 2) ‘multicomponent vs single intervention’ (two levels); 3) ‘instructor type’ (two levels: specialist led, teacher led); and 4) ‘the inclusion of Logan et al.’s [32] operational definitions’ (four levels) [32]. Meta-analysis of FMS data was not possible due to the variability in measurement methods and reporting of outcomes. Moderator 1 (two levels) is if a study measured FMS AND also satisfied at least one of Logan et al.’s [32] criteria. In this case the study had to satisfy both these criteria to be scored a ‘YES’. If a study measured FMS and did not satisfy a minimum of one of Logan et al.’s [32] criteria they scored a ‘NO’. Moderator 4 (4 levels) was to assess if there was a difference in the outcome dependent on the number of Logan et al.’s [32] criteria that were satisfied according to the four levels: 1) 0 criteria = level 1; 2) 1 criteria = level 2; 3) 2 criteria = level 3; 4) 3 criteria = level 4. Moderator #4 does not require a measure of FMS to satisfy any of the levels.

We derived the threshold for minimal clinically important difference (MCID) for this study by using an anchor-based approach using data from recent cross sectional [56] and longitudinal [10, 57-58] studies. Each of these studies reported daily changes in MVPA levels, measured using accelerometry, for each year of childhood. We used the reported daily change in MVPA levels from each of these studies to calculate the average decrease in MVPA per day, per...
year of age. We calculated that participation in MVPA decreases on average by 3.6 ± 0.5 minutes per day (mean ± SD), for each year of age across childhood (average across the aforementioned studies). Therefore, we define the MCID for this study as a mean difference of 3.6 minutes (intervention minus control) as any increase in MVPA above this amount could be considered as reversing the current decline in MVPA levels that occur throughout childhood.

To provide the expected range of the true effect (difference between intervention and control) likely in a comparable future studies we calculated a 95% prediction interval [59]. Furthermore, using the methods described in Mathur and VanderWeele [60], we calculated the proportion of future studies (with 95% CI) that are likely to achieve an effect that is above our threshold for a MCID (3.6 minutes of MVPA) and below the second threshold on the opposite side of the null (-3.6 minutes of MVPA).

3. Results

Searches of electronic databases yielded 25,697 articles. An additional 17 articles were identified from reference lists of eligible articles. Figure 1 provides the PRISMA flow diagram with reasons for study exclusion. Exclusion codes and their respective descriptions can be reviewed in Table 1.

3.1 Participants

Eligible studies (n = 19 studies) were conducted across 305 primary schools/community centres with a combined population sample size of n = 10,412 (41% to 53% male; range). Participants were 5 to 11 years old (n = 19 studies), between 118 cm and 143 cm in height (n = 8 studies) and weighed 24.4 kg to 49.9 kg (n = 7 studies). The percentage of participants classified as overweight/obese ranged from 21% to 46% overweight/obese (n = 6 studies).

Intervention participants (n = 5,106; 43% to 53% male) were 6.3 to 10.7 years old, while control participants (n = 4,670; 33% to 56% male) age range was 6.3 to 10.6 years old. Of the 19
eligible studies, 14 were suitable for meta-analysis and contributed control and intervention
data for minutes of MVPA for baseline and post study (mean ± SD); change scores (post –
baseline; mean ± SD); or mean difference (95%CI; intervention – control). Meta-analysis was
completed on n = 4,040 participants (Intervention n = 2,096; control n = 1,944) from 210
schools/community centres.
Figure 1 PRISMA Flow diagram with coded reasons for exclusion. Exclusion codes: X = irrelevant topic; E1 = not original research; E2 = research design; E3 = participants outside of 5 to 11 years of age; E4 = special population; E5 = no identifiable FMS intervention; E6 = intervention setting; E7 = full text not available in English; E8 = did not report a measure of daily level of total or MVPA; E9 = No objective measure of physical activity. Full exclusion code descriptions can be seen in Table 1).

3.2 Qualitative synthesis

Table 2. outlines the key characteristics of the studies included in this review. Of the studies included, seven were conducted in the UK (37%), and five in Australia (26%), with three conducted in America, two conducted in Ireland and one each in Germany and Switzerland. Included studies consisted of 15 RCT (n = 13 cluster; 2 parallel) and four non-RCT (parallel).

3.2.1 Fundamental movement skills

Of the 19 studies included, five studies measured FMS at baseline and follow up using either; Test of Gross Motor Development (TGMD) 2.0 [47,61,67], Australian Department for Education manual [45], or the ‘CHECK’ test manual [63]. Four studies reported skill scores for two categories of FMS (LC, OC or LC, B) [47,61,63,67]. Overall FMS score was reported in four studies [45,47,61,67]. Of the five studies measuring FMS, one study reported inter-rater agreement [45], and one study reported inter and intra-rater reliability coefficients (Kappa) [61].
<table>
<thead>
<tr>
<th>Study name</th>
<th>Intervention details</th>
<th>Control group format</th>
<th>Study setting</th>
<th>Age (years)</th>
<th>Frequency Session per week</th>
<th>Intervention duration</th>
<th>Additional component</th>
<th>Intervention delivery method</th>
<th>Timing of initial outcome measurement</th>
<th>Follow up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adab et al. [48]</td>
<td>Multi component - PA intervention components - School staff were provided with training and resources to provide 30 minutes of additional MVPA on each school day. Villa Vitality programme of activities based on movement routines and ball skills session, at an English premier league football club</td>
<td>Usual curriculum</td>
<td>Primary school</td>
<td>5 - 7</td>
<td>Villa Vitality = 3 sessions in total over one term (6 weeks) 30mins MVPA = Every school day in year 2, within school time</td>
<td>2 years</td>
<td>Cooking workshops; information sheets sent home to parents; Resources provided to teachers. Interactive nutritional sessions, and an opportunity to practise cooking skills</td>
<td>Coaching staff at Aston Villa FC, teachers at school (following training)</td>
<td>3 months post intervention</td>
<td>Yes; 6 months post intervention/Decrease in MVPA</td>
</tr>
<tr>
<td>Barnes et al. [37]</td>
<td>Multi component - Education sessions with 60 minute PA sessions Incl. rough and tumble play and fundamental movement skills</td>
<td>Wait list control</td>
<td>Primary school</td>
<td>5 - 12</td>
<td>1 x session per week for 8 weeks - 60mins PA - 25mins theory</td>
<td>8 weeks</td>
<td>Separate mother &amp; daughter education sessions and PA homework</td>
<td>Researcher with PE qualification</td>
<td>2 weeks post intervention</td>
<td>Yes: 20 week follow up/Decrease in MVPA</td>
</tr>
<tr>
<td>Breslin et al. [64]</td>
<td>Sport For LIFE:AI – Practical sport and PA sessions; including activities focussed in movement skill development</td>
<td>Wait list control</td>
<td>Primary school</td>
<td>8 – 9</td>
<td>1 x 60mins per week</td>
<td>12 weeks</td>
<td>Not Applicable</td>
<td>Trained student volunteer from research institution</td>
<td>Midpoint (6 weeks) and immediately post (week 13)</td>
<td>Yes: 6 months post intervention/Increase in MVPA – no diff between groups</td>
</tr>
<tr>
<td>Caballero et al. [50]</td>
<td>Multi component - PE program based on the SPARK - implementing a minimum of three 30-minute sessions per week of MVPA.</td>
<td>Not reported</td>
<td>Primary School</td>
<td>7 - 8</td>
<td>3x30mins SPARK sessions per week</td>
<td>3 years</td>
<td>Classroom curriculum - eating behaviours and PA. Nutritional advice for school meals. Family action packs</td>
<td>Regular delivery of PE (Some PE teachers, some classroom teachers)</td>
<td>3 years (immediately post intervention)</td>
<td>No</td>
</tr>
<tr>
<td>Cohen et al. [61]</td>
<td>Multi component - PA and FMS intervention - SCORES program 1: teacher professional learning &amp; student leadership workshops. Implement 6 PA policies for promotion of PA and FMS within PE and school day.</td>
<td>Wait list control - Usual PE and school sport program</td>
<td>Primary school</td>
<td>7 - 10</td>
<td>Student workshop = 1 x 2 hour, Teacher workshop = 1 x full day &amp; 1 x half day.</td>
<td>12 months</td>
<td>Strategies to target home environment (newsletter, parent evening). Strategies to improve school-community links</td>
<td>Teacher trained to deliver with pupils attending workshops to help lead sessions</td>
<td>12 months</td>
<td>No; 6 month mid review/NA</td>
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<tr>
<td>Study</td>
<td>Intervention Description</td>
<td>Usual curriculum</td>
<td>Primary school</td>
<td>Duration</td>
<td>Outcomes</td>
<td>Control Group</td>
<td>Post intervention</td>
<td>Notes</td>
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<tr>
<td>Fairclough et al. [46]</td>
<td>1 x PE usual curriculum + 2 x BTM classes. The classes teach age appropriate movement skills designed to improve health related and skill-related fitness</td>
<td>Usual curriculum</td>
<td>Primary school</td>
<td>10 - 11</td>
<td>Not Applicable</td>
<td>Born to move specialist instructor (10 years’ experience)</td>
<td>6 Weeks; outcomes assessed during intervention period</td>
<td>No</td>
<td></td>
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</tr>
<tr>
<td>Jago et al. [71]</td>
<td>Action 3:30 After school PA programme - training teachers and assistants to deliver PA sessions following the FUNdamentals training programme to increase children’s fundamental movement skills</td>
<td>No after school program</td>
<td>Primary school</td>
<td>9 - 10</td>
<td>Not Applicable</td>
<td>Teaching assistant trained by Action3:30 researchers</td>
<td>20 weeks; outcomes assessed during intervention period</td>
<td>Yes; 4 month post intervention Decrease in MVPA</td>
<td></td>
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<tr>
<td>Jago et al. [62]</td>
<td>Action 3:30R After school PA programme - training teachers and assistants to deliver PA sessions. Sessions focussed on fun PA whilst improving FMS</td>
<td>No after school program</td>
<td>Primary school</td>
<td>8 – 10</td>
<td>Not Applicable</td>
<td>Teaching assistant trained by Action3:30 researchers</td>
<td>15 weeks; outcomes assessed during intervention period</td>
<td>No</td>
<td></td>
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<tr>
<td>Johnstone et al. [47]</td>
<td>The Go2Play Active Play intervention – structured games and free play with a variety of FMS <a href="http://www.Activeplay.org.uk">www.Activeplay.org.uk</a></td>
<td>Usual curriculum</td>
<td>Primary school</td>
<td>6 - 8</td>
<td>Not Applicable</td>
<td>Play workers from external company (<a href="http://www.agileCIC.com">www.agileCIC.com</a>)</td>
<td>5 months from baseline; outcomes assessed during intervention period</td>
<td>No</td>
<td></td>
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</tr>
<tr>
<td>Johnstone et al. [65]</td>
<td>Active play intervention (formally Go2Play) games designed to develop participants FMS <a href="http://www.actify.org.uk/activeplay">www.actify.org.uk/activeplay</a></td>
<td>Wait list control</td>
<td>Primary school</td>
<td>7 - 8</td>
<td>Not Applicable</td>
<td>Play workers from external company (<a href="http://www.agileCIC.com">www.agileCIC.com</a>)</td>
<td>Immediately post intervention (week following)</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kriemler et al. [70]</td>
<td>Multi component - PE classes additional to current curriculum - The intervention group had two additional physical education lessons on the remaining school days in addition to current curriculum.</td>
<td>Usual curriculum</td>
<td>Elementary school</td>
<td>6 - 11</td>
<td>Not Applicable</td>
<td>2 x 45 mins were delivered by specialist PE teacher. The 3x45 mins by standard classroom teacher</td>
<td>9 months; Outcomes measured over 3 weeks, during intervention period</td>
<td>Yes; 3 years post intervention Decrease in MVPA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Martin and Murtagh [68]</td>
<td>The Active Classrooms program behaviour change intervention to train and enable primary teachers to change their teaching methods</td>
<td>Wait list/delayed treatment</td>
<td>Primary school</td>
<td>8 – 12</td>
<td>Not Applicable</td>
<td>Teacher trained</td>
<td>8 weeks; immediately</td>
<td>Yes; 8 weeks post intervention</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Intervention Type</td>
<td>Curriculum</td>
<td>Grade Level</td>
<td>Duration</td>
<td>Frequency</td>
<td>Follow-up</td>
<td>PE Lead</td>
<td>Measures Taken</td>
<td>MVPA Effect</td>
<td></td>
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<tr>
<td>Sallis et al. [66]</td>
<td>2 arm PE intervention (delivery type) - SPARK PE. A typical SPARK lesson had two parts: health-fitness activities and skill-fitness activities</td>
<td>Usual curriculum</td>
<td>Primary school</td>
<td>9 - 10</td>
<td>3 x 30mins per week (15mins x HRF, 15mins x Skill)</td>
<td>2 years</td>
<td>Not Applicable</td>
<td>Arm 1 - specialist led; Arm 2 - teacher led</td>
<td>Increase in MVPA</td>
<td></td>
</tr>
<tr>
<td>Salmon et al. [45]</td>
<td>FMS intervention focused on six skills, including three object control skills (overhand throw, kick and strike) and three locomotor skills (run, dodge and vertical jump). Most lessons focused on at least two skills, and each skill was a focus in at least six or more sessions</td>
<td>Usual curriculum</td>
<td>Primary School</td>
<td>10 – 11</td>
<td>19 x 40-50mins once per week</td>
<td>19 weeks</td>
<td>Not Applicable</td>
<td>PE teacher</td>
<td>19 weeks (immediately post intervention); Yes; 6 and 12 months follow up; Decrease in MVPA</td>
<td></td>
</tr>
<tr>
<td>Sutherland et al. [69]</td>
<td>Multi component - Teaching strategies to improve PE lesson quality. Schools were provided with PA equipment and encouraged to offer supervised PA at breaks. Sixth-grade students were encouraged to become school PA leaders and set up, run, and pack away games. All classroom teachers were offered a 90-minute professional learning workshop focused on delivery of FMS to students, strategies to improve lesson quality through student engagement and increase students’ MVPA.</td>
<td>Usual curriculum</td>
<td>Primary school</td>
<td>9 - 11</td>
<td>Student workshop = 1 x 2 hour; Teacher workshop = 1 x full day &amp; 1 x half day.</td>
<td>6 months</td>
<td>School PA policy review and parental engagement through newsletter and school website promotion. Improvements to community links</td>
<td>Peer teaching with experienced health promotion staff with PE background. Teachers were trained in line with SAAFE principles</td>
<td>6 months; over the course of 3-4 months; No</td>
<td></td>
</tr>
<tr>
<td>Taylor et al. [49]</td>
<td>Multi component – PA included Active breaks (AB), bounce at the bell, ‘Born To Move’ (BTM) and PA playground challenge cards.</td>
<td>Usual curriculum timetabled breaks</td>
<td>Primary School</td>
<td>9 - 10</td>
<td>AB = 1 x 5mins per day. Bounce at the bell = 3 x 1-2mins per day. BTM = 2 x 10mins per week. Playground cards = 5 min/game every break time.</td>
<td>8weeks</td>
<td>PA homework and newsletters. The Daily mile (1 x 15 min per day). Teacher training.</td>
<td>Sports coach or PE teacher normal delivery</td>
<td>2 months; (week following final sessions); No</td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Intervention Description</td>
<td>Usual curriculum</td>
<td>Primary school</td>
<td>8 - 12</td>
<td>2 x 45mins per week over 4 years (68 lessons per year). The 90mins per week was added to the remaining curriculum taught PE to make up the 150mins per week.</td>
<td>4 years (data collected at the end of each year)</td>
<td>Not Applicable</td>
<td>Five university qualified PE teachers training from Blue-earth</td>
<td>End of intervention period _ no other details provided</td>
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<tr>
<td>Telford et al.</td>
<td>The Intervention consisted Fitness, coordination and Agility; Gymnastic-based activities; Skill activities including group and individual practices to develop movement skills; Games designed to promote aerobic fitness, cooperation and teamwork; Core movement including yoga-like practices to develop muscular strength, flexibility, balance and postural control</td>
<td>Usual curriculum</td>
<td>Primary school</td>
<td>8 - 12</td>
<td>2 x 45mins per week over 4 years (68 lessons per year). The 90mins per week was added to the remaining curriculum taught PE to make up the 150mins per week.</td>
<td>4 years (data collected at the end of each year)</td>
<td>Not Applicable</td>
<td>Five university qualified PE teachers training from Blue-earth</td>
<td>End of intervention period _ no other details provided</td>
<td></td>
</tr>
<tr>
<td>Weber et al.</td>
<td>Multi-component - “Fitness Fur Kids” - exercise program with extensive movement training and high levels of MVPA</td>
<td>Not reported</td>
<td>Primary school</td>
<td>9 - 10</td>
<td>2 x 45mins additional PE sessions per week using the Fitness Fur Kids plans</td>
<td>10 months</td>
<td>Diet - 10 school lessons (1/month) related to nutrition. Extra-curricular - soccer training session, visits from local/national sports teams.</td>
<td>Physical component taught by qualified trainers</td>
<td>Mid intervention only at 6 months</td>
<td></td>
</tr>
<tr>
<td>Wong et al.</td>
<td>Multi-component - after school - The intervention group received structured PA- using: hurdles, BOSU balls, jump ropes, medicine balls, obstacle course, broom balls, urban rebounders, team resistance rings, agility rings, cone drills, hula hoops, soft foam balls, agility ladders, reaction balls, parachute play</td>
<td>Regular after school programs</td>
<td>Community centres</td>
<td>9 - 12</td>
<td>2 x 90mins/week for 6 weeks (then repeated)</td>
<td>3 x 6 week blocks</td>
<td>30 minutes of theory twice per week. Intervention group completed a final block of water based activity</td>
<td>Trained program staff</td>
<td>Measurements taken at the end of each 6 week block</td>
<td></td>
</tr>
</tbody>
</table>

BTM = born to move; FMS = fundamental movement skills; HRF = health related fitness; MVPA = moderate to vigorous physical activity; PA = physical activity; PE = physical education; SAAFE = supportive, active, autonomous, fair, enjoyable; SCORES = supporting children’s outcomes using rewards, exercise and skills; SPARK = sports, play and active recreation for kids
3.2.2 Physical activity

Measurement methods for physical activity and the associated data handling techniques from included studies can be seen in Table 3. All of the included studies used accelerometers with data presented as counts per minute (cpm), percentage time spent in different activity thresholds (sedentary, light, moderate and vigorous, moderate-to-vigorous), or minutes spent in each activity threshold. Thirteen studies stated the cut points used for activity thresholds [37,45-47,49,61,62,64,65,68,69,71,72].

3.2.3 Outcome measurement and follow up

The duration of the intervention periods ranged from six weeks to four years. Of the 19 studies included, seven studies collected initial outcome data within two weeks of the intervention finishing [37,45,49,50,64,65,68], two studies collected data between two weeks and three months [48,69], six studies collected data during the final weeks of the intervention period [46,47,62,63,68,71] and four studies did not report a time frame for outcome assessment [61,66,67,72]. Follow up assessment was completed in nine studies [37,45,48,64,68,70,71], ranging from six weeks post intervention to three years post intervention.
Table 3. Physical activity measurement methods and FMS tools used in the studies included in this review, in alphabetical order.

<table>
<thead>
<tr>
<th>Study</th>
<th>PA measurement method</th>
<th>MVPA Output</th>
<th>Cut points used for activity thresholds</th>
<th>Measured FMS</th>
<th>FMS tool used</th>
<th>FMS outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adab et al. [48]</td>
<td>Accelerometer (uniaxial)</td>
<td>Minutes</td>
<td>Not reported</td>
<td>No</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Barnes et al. [37]</td>
<td>Accelerometer (triaxial)</td>
<td>CPM</td>
<td>SED 0-100; LPA 101-2292, MPA 3581-6129; VPA &gt;6130cpm †2</td>
<td>No</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Breslin et al. [64]</td>
<td>Accelerometer (triaxial)</td>
<td>Minutes</td>
<td>MPA 2293-4008; VPA &gt;4008cpm †5</td>
<td>No</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Caballero et al. [50]</td>
<td>Accelerometer (triaxial)</td>
<td>CPM</td>
<td>Not reported</td>
<td>No</td>
<td>-</td>
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<tr>
<td>Cohen et al. [61]</td>
<td>Accelerometer (triaxial)</td>
<td>Minutes</td>
<td>SED 0-100; LPA 101-2292, MPA 2293-4008; VPA &gt;4008cpm †2</td>
<td>Yes</td>
<td>TGMD 2</td>
<td>LC, OC skill score and FMS overall</td>
</tr>
<tr>
<td>Fairclough et al. [46]</td>
<td>Accelerometer (triaxial)</td>
<td>Minutes</td>
<td>SED &lt;113; LPA 306-817; MPA = 818-1968, VPA &gt;1969, MVPA = &gt;818 †3</td>
<td>No</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jago et al. [71]</td>
<td>Accelerometer (triaxial)</td>
<td>Minutes</td>
<td>SED 0-100; LPA 101-2292, MPA 2293-4008; VPA &gt;4008cpm †2</td>
<td>No</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jago et al. [62]</td>
<td>Accelerometer (triaxial)</td>
<td>Minutes</td>
<td>SED 0-100; LPA 101-2292, MPA 2293-4008; VPA &gt;4008cpm †2</td>
<td>No</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Johnstone et al. [47]</td>
<td>Accelerometer (triaxial)</td>
<td>CPM</td>
<td>SED 0-100; LPA 101-2292, MPA 2293-4008; VPA &gt;4008cpm †2</td>
<td>Yes</td>
<td>TGMD 2</td>
<td>LC, OC Skill score, FMS overall and</td>
</tr>
<tr>
<td>Johnstone et al. [65]</td>
<td>Accelerometer (triaxial)</td>
<td>% time</td>
<td>SED 0-100; LPA 101-2292, MPA 2293-4008; VPA &gt;4008cpm †2</td>
<td>Yes</td>
<td>TGMD 2</td>
<td>LC, OC Skill score, FMS overall and</td>
</tr>
<tr>
<td>Kriemler et al. [70]</td>
<td>Accelerometer (uniaxial)</td>
<td>Minutes</td>
<td>Not reported</td>
<td>No</td>
<td>-</td>
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<tr>
<td>Martin and Murtagh [68]</td>
<td>Accelerometer (triaxial)</td>
<td>Minutes</td>
<td>SED 0-100; LPA 101-2292, MPA 2293-4008; VPA &gt;4008cpm †2</td>
<td>No</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sallis et al. [66]</td>
<td>Accelerometer (uniaxial)</td>
<td>CPM</td>
<td>Not reported</td>
<td>No</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Salmon et al. [45]</td>
<td>Accelerometer (uniaxial)</td>
<td>Minutes</td>
<td>LPA &lt;1951; MPA 1952-5724; VPA&gt;5725 †1</td>
<td>Yes</td>
<td>Australian dept. for ed.</td>
<td>FMS overall – GMQ z score</td>
</tr>
<tr>
<td>Study Authors</td>
<td>Type of Instrument</td>
<td>Measure of Activity</td>
<td>Activity Definition (if applicable)</td>
<td>Compliance</td>
<td>Additional Information</td>
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<tr>
<td>Sutherland et al. [69]</td>
<td>Accelerometer</td>
<td>Minutes</td>
<td>SED 0-100; LPA 101-2292, MPA 2293-4008; VPA &gt;4008cpm †²</td>
<td>No</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Taylor et al. [49]</td>
<td>Accelerometer</td>
<td>Minutes</td>
<td>Vector magnitude, measured in mg – SED &lt;50mg; LPA 51-200mg; MPA 201-706mg; VPA</td>
<td>No</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Telford et al. [72]</td>
<td>Accelerometer</td>
<td>Minutes</td>
<td>SED 0-100; LPA 101-2292, MPA 2293-4008; VPA &gt;4008cpm †²</td>
<td>No</td>
<td>-</td>
<td></td>
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<tr>
<td>Weber et al. [63]</td>
<td>Accelerometer</td>
<td>Minutes</td>
<td>Not reported</td>
<td>Yes</td>
<td>CHECK test, LC, OC skill scores and CHECK mean</td>
<td></td>
</tr>
<tr>
<td>Wong et al. [67]</td>
<td>Accelerometer</td>
<td>% time</td>
<td>Not reported</td>
<td>No</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

†¹ – Freedson et al. [73]; †² - Evenson et al. [74]; †³ - Chandler et al. [75]; †⁴ - Hildebrand et al. [76]; †⁵ – Mattocks et al. [77]; MVPA = Moderate to vigorous physical activity; FMS = Fundamental movement skills; LC = Locomotor; OC = Object control; B = Balance; SED = Sedentary; LPA = Light physical activity; MPA = Moderate physical activity; VPA = Vigorous physical activity; CPM = counts per minute; KTK = Kӧrper-koordination Test für Kinder; POC = Process orient Checklist; TGMD –
3.2.4 Risk of Bias

The summary of the risk of bias assessment for RCT and non-RCT studies are presented in Figure 2 and Figure 3, respectively. The bias domain which resulted in most of the ‘high risk’ classifications was section 1 of the RoB2.0 and section 3 and 4 of the ROBINS-I assessments. In both cases these sections relate to the assessment of bias due to randomisation, missing outcome data and possible deviation from the intended intervention. Four studies [47,50,67,70] scored as either ‘some concerns/moderate’ or ‘high/serious risk’ of bias due to the handling of missing data and not blinding outcome assessors. Baseline imbalances, due to either the randomisation process (RoB2.0) or not controlling for confounders (ROBINS-I) was responsible for four RCT [61,65,69,70] and two non-RCT [46,47] studies scoring as either ‘some concerns/moderate’ or ‘high/serious risk’ of bias. One RCT scored ‘high risk’ for multiple analyses of the data, however this score was given as it was hard to gain clarification due to data protection laws prohibiting access [50]. Of the 19 studies included 53% (n = 10) received an overall score of ‘low risk’ [37,48,49,62,63,64,68,69,71,72].

![Figure 2. Risk of Bias assessment for Randomised Control Trials; 1) Bias arising from the randomization process; 1b) Bias arising from the timing of identification and recruitment of individual participants in...](image-url)
relation to timing of randomization (ONLY CLUSTER RCT); 2) Bias due to deviations from intended interventions; 3) Bias due to missing outcome data; 4) Bias in measurement of the outcome; 5) Bias in selection of the reported result

Figure 3. Risk of Bias assessment for Non-Randomised Controlled Trials

The individual study scores for the ROBINS-I and the RoB 2.0 can be seen in supplementary tables S2 and S3 (Supplementary material appendix S1), respectively.

3.3 MVPA Data synthesis

Random effects meta-analysis resulted in a pooled mean difference of 4.3 minutes (95%CI; -0.3 to 8.8) in favour of the intervention group. The between study variability, expressed as Tau (Ƭ), was 7.6 minutes. The 95% prediction interval; the effect that is likely to be expected in a future study was -13 to 21 minutes. The percentage of future studies that are likely to be above our MCID threshold of 3.6 minutes of MVPA is 47% (95%CI; 22 to 70) with a percentage of future studies that are likely to find an effect in the opposite direction (i.e., -3.6 minutes) of 15% (0 to 39). Publication bias due to possible small study effects was evident on examination of the funnel plot (SE/mean difference) with an Egger’s regression coefficient of 1.8 (95%CI,
-0.7 to 4.4), with smaller studies having the largest treatment effects and a higher number favouring the control/alternative treatment group.

3.4 Meta-regression

**Model 1**

Exploratory Meta-regression analyses revealed a coefficient (difference in means) of 13.3 minutes of MVPA per day (95%CI; 8.0 to 18.6) in favour of the studies that combined a measure of FMS with at least one of Logan et al.’s criteria [32], with an improvement in study heterogeneity (Ƭ = 2.5 minutes). A significant effect was found for model one (F = 930.0, df = 1, dfErr = 12, p = 0.0001), explaining 89% of the variability between studies (R² = 0.89) (supplementary material Appendix S2).

Model 1 equation: If a measure of FMS used with at least one of Logan et al.’s criteria [32]

Intercept = 1.1565

Y = 1.1565 + 13.3188

**Model 2**

Meta-regression examining the use of Logan et al.’s three criteria [32] revealed an additive effect (linear increase) for the number of criteria used. The use of at least one criteria had a negligible effect on minutes of MVPA (-0.09 min/day; -5.8 to 5.7), whilst the use of two (9.5 min/day; 1.4 to 17.6) and three (15.7 min/day; 8.9 to 22.6) had a substantial positive effect on minutes of MVPA. A significant effect was found for model 2 (F = 11.2, df = 3, dfErr = 10, p = 0.0016), explaining 89% of the variability between studies (R² = 0.89). Model 2 also resulted in a reduction in between study variability (Ƭ = 2.5 minutes) (supplementary material Appendix S2).

Model 2 equation: Intercept = 1.1815

If one Logan et al. criteria used; Y = 1.1815 – 0.0920
If two Logan et al. criteria used; $Y = 1.1815 + 9.5185$

If three Logan et al. criteria used; $Y = 1.1815 + 15.7346$

**Additional models**

Instructor type ($R^2 = 0.2; \tau = 7.5$) explained very little of the between study variance whilst the use of multicomponent interventions ($R^2 = 0.0; \tau = 7.6$) did not explain any of the between study variance (Appendix S2). Meta-regression using study quality as a moderator was deemed inappropriate due to the low number of studies in each category.

**4. Discussion**

Fundamental movement skills are considered an important prerequisite for physical activity participation [19]. This systematic review and meta-analysis aimed to establish the effectiveness of FMS interventions at improving daily MVPA levels in primary school children. A key finding was that FMS interventions improve daily levels of MVPA by 4.3 minutes/day (pooled effect), exceeding the MCID threshold set for this study (3.6 minutes/day). This indicates that the inclusion of an FMS intervention is likely to improve children’s daily levels of MVPA. However, the intervention effects varied considerably between the 14 studies (range - 1 to 18 minutes between group differences). The typical between study variability (Tau) of 7.6 minutes MVPA shows the substantial heterogeneity, and results in wide prediction intervals for future studies. Meta-regression identified studies that included both a measure of FMS and a minimum of one criteria from Logan et al.’s [32] operational definition of FMS reduced the between study variability (tau) to 2.5 minutes and increased the effect size to 13.3 minutes/day.

Very few of the studies included in the meta-analysis of MVPA measured FMS as an outcome variable (n=4). Of the 19 studies included in the qualitative synthesis, five measured FMS as an outcome (Table 2) and four out of these five studies reported positive effects of the intervention on physical activity outcomes. For studies to include a measurement of FMS
implies that the intervention designers in the aforementioned studies have an understanding that the mastery of FMS goes beyond the phylogenetic development of a child’s physical growth [19] and therefore are likely to have put a larger emphasis on providing developmentally and instructionally appropriate FMS activities [78]. The inclusion of at least one of Logan et al.’s [32] criteria in a study suggests the authors identified the need to be explicit in their classification of FMS. This point is supported further by the outcomes from the categorical (4 levels) meta-regression exploring the effect of including an operational definition of FMS using the three criteria set out in Logan et al. [32]. If no criteria were used (Intercept/level1) there was an expected effect of 1.18 minutes with a trivial (-0.09) decrease expected if only one criteria were used. However, if two or three criteria were used, meaning the authors attempted to fully conceptualised FMS using Logan et al.’s criteria [32], then there was an expected increase of 9.5 and 15.7 minutes of MVPA, respectively. It should be noted here that these data are exploratory, and due to a small number of studies (n=6) using a measure of FMS or Logan et al.’s [32] criteria, cautious interpretation is advised [79].

Including FMS activities without an explicit description of how FMS contribute to the development of movement competence, and with the expectation that children will naturally become proficient, ignores much of the evidence surrounding the delivery and instruction of FMS. Furthermore, incorporating traditional FMS activities (e.g., jumping, throwing) within the intervention with the hope children will improve naturally over time disagrees with much of the pedagogical research surrounding FMS [14, 19, 78, 80]. The development of FMS is analogous to the way a child learns to read and write [14]. Without prior teaching of letters and their phonemes, children are less likely to be able to structure more complex words and sentences. Similarly, children who do not develop the most basic FMS are unlikely to possess the movement repertoire necessary when faced with more demanding tasks. Moreover, providing children with free-play opportunities [47] and providing games and equipment [69, 76] is unlikely to have the automatic consequence of improved FMS [19, 32, 78], in the same way providing children with a library of books does not result in an advanced reading ability.
A review by Lubans et al. [23] found strong evidence for a positive association between FMS competency and physical activity in children and adolescents. However, due to a variety of research designs in the included studies (e.g., cross sectional, longitudinal and experimental) and the limited number studies measuring FMS and physical activity in children (n=4), Lubans et al.’s review [23] resulted in a combined data set for children and adolescents. Therefore, this review could not differentiate between the childhood and adolescent importance of FMS for physical activity participation. The age range of participants included in our meta-analysis was 5 to 11 years of age, highlighting the importance of FMS for physical activity participation in primary school children. Supplementary to the pooled intervention effect in this meta-analysis, we estimated that half of all future studies (47%) should expect to find an effect greater than the MCID, emphasising the potential for FMS interventions to increase childhood levels of MVPA.

Our results agree largely with recent reviews [25, 81] regarding the variability in intervention implementation. There was substantial variability in the methods utilised in the interventions of included studies in this review (Table 2 and 3). Firstly, there was disparity in the number (multi-component) and type of components in the interventions with 9 of the 19 included studies reporting the use of a multicomponent intervention. Secondly, the level of instruction varied considerably between studies, reporting the use of either the schoolteachers (teacher led), school pupils (peer led) or specialist PE teachers/coaches. However, meta-regression using instructor type, and the use of multicomponent interventions as a moderator did not explain any of the heterogeneity between studies. This is contrary to findings from a recent review [25], which reported study heterogeneity was reduced when studies were conducted by an FMS specialist three or more times per week for six months. This contrast in findings implies that the inclusion of an FMS specialist instructor is not enough on its own to improve FMS and physical activity levels, rather it is the combination of an FMS specialist and the appropriate volume and duration of the intervention components [25], with higher volume/duration increasing the opportunity to master the skills.
The aforementioned insights are important when considering the design of an FMS intervention. However, Engel et al. [25] were unable to quantify the effect of FMS interventions on daily levels of MVPA in primary school aged children. The MVPA effects presented by the authors are inclusive of both preschool and primary school age studies. Further Engel et al. [25] grouped studies focusing on overweight populations with studies without a specific focus on weight status. Lastly, the authors combined outcomes from studies using different MVPA measurement tools (accelerometer, pedometers and observation) and time frames (class time only, school day and whole day) in their analyses. Although an attempt was made to meta-analyse studies by using the standardised mean difference (SMD), this does not account for study differences that are a result of the strong moderating effects of age and weight status in the FMS/physical activity relationship, previously identified in the literature [27]. The use of SMD in meta-analysis has also been criticised due to common disagreements in data extraction and high rates of errors, often resulting in outcomes that negate the findings of the analyses [82,83]. Our study excluded articles which had a specific focus on a population group with specific health conditions (e.g., overweight/obese, developmental disorders) and preschool aged children. Furthermore, we only included studies in our meta-analysis that reported daily levels of MVPA in minutes per day, enabling us to explore the absolute difference in means and avoid the errors associated with SMD.

The heterogeneity established in this review may be further explained by the biases present in the reporting of study outcomes. Studies included in this review were identified as having biases due to 1) the contamination of groups; 2) blinding of assessors; and 3) the handling of missing data. We agree with Engel et al. [25], that the blinding of participants in an intervention study is not always possible and in younger age groups is unlikely to have an effect on the outcome. Although meta-regression using study quality as a moderator was not possible due to small number of studies in each category, we advise caution when interpreting results from studies with subjective measures that did not blind outcome assessors. Further, certain skills in a battery of FMS tests are more problematic to assess [84], therefore, the type of skills
measured in the measurement battery chosen is likely to elicit different results dependent on
the reliability of the assessors. Of the five studies that measured FMS, only one reported
inter-rater and intra-rater reliability for the baseline and outcome assessors. Adequate reliability
and reporting of the reliability data is essential for accurate interpretation of FMS outcomes to
ensure any change in data from baseline to outcome assessment is a result of the intervention
and not to extraneous variables.

4.1 Future recommendations for reporting of outcomes

Fourteen studies in this review did not include a measure of FMS. Furthermore, when referring
to Logan et al.’s [32] recommended criteria for an operational definition of FMS, six of the 19
studies included in this review documented one of the three definitions [45,61,62,65,69,71]
and only one study was recorded as including all three FMS criteria [61]. We reinforce these
recommendations, and advise future studies including FMS to include an operational definition
of FMS, incorporating specific skill categories and specific examples of FMS relevant to the
study, as highlighted in Logan et al. [32].

Future studies should equally consider the effect of completing outcome assessments during
the intervention period, particularly inclusive of days when the intervention sessions took
place. Of the 19 studies included, six studies completed outcome assessment during the
intervention period [46,47,62,63,68,71]. The MVPA levels reported in these studies is likely
due to the increased activity levels of the children during the intervention sessions, and not a
true representation of the intervention effect. McEwan et al. [85] stated that as a field we have
a comprehensive understanding of how to enhance physical activity during the course the
intervention period but lack the necessary understanding of how to make a sustained
improvement in physical activity once the intervention has ended. Seven studies in this review
conducted a follow up, many of which (n=5) noted a reversal or decline in the positive MVPA
effects following the termination of the intervention (Table 2). The decline in intervention
effects from post intervention to follow up are believed to become more pronounced as the
time between post assessment and follow up increases [85]. Therefore, it is recommended that future studies include a follow up period to identify any post intervention decline, and also to develop methods to support a sustained improvement in physical activity levels once the official intervention period is over.

Moreover, the timing of outcome measurements is important from a movement development perspective. The duration of time taken to complete outcome assessment in the proportion of studies (37%) that completed follow up assessments ranged from one week to three months (Table 2). Outcomes assessed immediately following the completion of the intervention (post-test) represent an immediate motor learning response (‘performance’) [86] to the FMS activities included in the intervention, particularly in studies of relatively short durations (six to eight weeks). Follow up measures, often used as a retention test when measuring FMS, evaluate more permanent results in the movement ‘development’ [86] of the child. However, of the seven studies in this review completing follow up assessments, only one measured FMS at post-test and follow up [45]. For this reason, ascertaining a relationship between true FMS ‘development’ and MVPA levels would be erroneous. Future studies should consider including both an FMS ‘performance’ and FMS ‘development’ evaluation alongside objectively measured MVPA to acquire a greater understanding of the relationship between FMS and MVPA over time. This is in agreement with Barnett and colleagues [87] recent review on longitudinal evidence to support Stodden et al.’s model. Barnett et al. identified a need for experimental studies that examine change in motor competence relative to change in the other constructs (i.e., physical activity) and confounding factors (i.e., weight status), tracked over multiple time points throughout childhood and adolescence [87].

Finally, the different placement of the accelerometers to measure physical activity in the included studies in addition to the variety of cut-points used might have contributed to mixed findings concerning the contribution from the FMS in the intervention activities. Future studies measuring the effect of FMS activities on physical activity levels in children should consider
using appropriate methods for the placement of measurement devices and associated, data handling methods [88].

4.2 Strengths and limitations

This review complied with a predefined study protocol (Prospero) and employed a comprehensive search strategy, a thorough selection and screening strategy and adhered to the PRISMA protocol for systematic reviews [39]. There was substantial heterogeneity noted, resulting in wide confidence intervals and large between study variability, therefore; as for most meta-analysis, caution is warranted in interpreting the prediction intervals presented [89]. The heterogeneity noted also disguises the fact that there are large effect sizes in some of the studies included [51]. For this reason, we applied contemporary metrics [60], which express the estimated proportion of future studies with expected effects above and below a defined threshold, in this case the MCID of 3.6 minutes of MVPA. Furthermore, we were able to explain a large proportion of the between study heterogeneity using meta-regression models. Meta-regression identified that studies which accurately conceptualised and measured FMS substantially improved the intervention effect with reduced heterogeneity. However, caution in interpretation of results should be applied due to the small number of studies included in the analyses [51,79]. Furthermore, the authors acknowledge that the restrictive word counts may have limited a detailed definition of FMS in the articles included in this review and these findings are based on how authors of the included studies reported FMS. However, in the absence of additional criteria, this study serves the purpose of highlighting the need for improvements in the clarity of reporting in relation to FMS research and also the need for more single component FMS interventions with a specific focus of FMS and PA outcomes in primary school aged children.

Eggers regression coefficient and its uncertainty revealed a possible small study bias, with smaller studies resulting in larger individual study treatment effects and also having a higher number of studies favouring the control group. However, caution is advised when interpreting
these small study effects due to the aforementioned heterogeneity noted in this meta-analysis. Finally, the decision to include only studies that reported daily minutes of MVPA may have underestimated the true effects on physical activity (i.e. total physical activity) of a FMS intervention in this population. However, the incongruity in the reporting of physical activity outcome data across studies (Table 3) is problematic and would only serve to obscure the relationship between physical activity levels and FMS competence.

5. Conclusion

Based on the results of this meta-analysis and narrative synthesis, the inclusion of FMS activities to a physical activity intervention aiming to improve daily levels of MVPA in 5 to 11 year old children is advocated. However, we conclude that comparable future studies focussing on FMS interventions should concentrate on establishing an accurate conceptualisation of FMS and how FMS will be integrated within their interventions. This would likely enhance study outcomes and improve clarity in communication from researchers specifically examining FMS. Furthermore, including a measure of FMS at regular intervals throughout the intervention would serve to potentially reverse the current decline in physical activity levels observed during childhood. Though this may seem time consuming from a school resource perspective, it would ensure that the included activities for the duration of the intervention period (or school term/year) are developmentally appropriate and accompanied with the relevant level of instruction and coaching. Adequate consideration should also be given to the research design, methods used to evaluate FMS, and an appropriate follow up period.

Data availability

All data generated or analysed during this study are included in this published article and its supplementary information files. All software code used in the meta-analysis and models underpinning the meta-regressions are available in the supplementary files (Appendix S1, Appendix S2 and Appendix S3).
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Declarations

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Conflicts of Interest

Michael Graham, Liane Azevedo, Matthew Wright and Alison Innerd declare that they have no conflicts of interest relevant to the content of this review.

Author contributions

MG had the idea for the review article. All authors were involved in the design of the protocol for the review (MG, LA, MW and AI). MG, LA and AI conducted all searches, completed selection and extracted data. Data for the meta-analysis was compiled by MG and analysed by MG. The draft manuscript was prepared by MG, critically revised by LA, MW and AI. All authors read and approved the final manuscript.

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