Article:

Eddy, LH, Wood, ML, Shire, KA et al. (5 more authors) (2019) A systematic review of randomized and case-controlled trials investigating the effectiveness of school-based motor skill interventions in 3- to 12-year-old children. Child: Care, Health and Development, 45 (6). pp. 773-790. ISSN 0305-1862

https://doi.org/10.1111/cch.12712

Child: care, health and development

A systematic review of randomised and case-controlled trials investigating the effectiveness of school-based motor-skill interventions in 3-12 year-old children

Journal:	*Child: Care, Health & Development*
Manuscript ID	CCH-2018-0401.R1
Manuscript Type:	Review Article
Keywords:	Child Development, Motor Coordination, Interventions, Systematic Review, School

ABSTRACT

Background: Research suggests that children identified with impaired motor skills can respond well to intensive therapeutic interventions delivered via occupational and physical therapy services. There is, however, a need to explore alternative approaches to delivering interventions outside traditional referral-based clinic settings because limited resources mean such health services often struggle to meet demand. This review sets out to systematically assess the evidence for and against school-based interventions targeted at improving the motor skills of children aged between 3-12 years old.

Method: Five electronic databases were searched systematically (AMED, CINAHL, Cochrane, Medline & PsycINFO) for peer-reviewed articles published between January 2012 and July 2018. Studies were eligible if they implemented a school-based motor skill intervention with a randomised or case-controlled trial design that objectively measured motor skills as an outcome, which were not specific to an athletic or sporting skill. Participants had to be aged between 3-12 years old and free from neurological disorders known to affect muscle function. Risk of bias was assessed using the Cochrane risk of bias tool.

Results: Twenty-three studies met the inclusion criteria. These studies encompassed interventions targeted at training: fundamental movement skills; handwriting; fine; and global motor skills. The majority of these studies reported beneficial impact on motor function specifically, but some interventions also assessed subsequent impacts on activity and participation (but not wellbeing). A number of the studies had methodological shortcomings that means these results need to be interpreted with caution.

Conclusions: Schools appear to be an effective setting for motor skill interventions, but the extent of benefit likely depends on the type of intervention. Moreover, confirmation is needed as to whether benefits extend beyond motor function into everyday activities, participation and wellbeing. Future research should include follow-up measures to assess the longer-term efficacy of school-based interventions.

INTRODUCTION

Children with motor difficulties are at a heightened risk of experiencing physical and mental ill-health sequelae (Lingam et al., 2012; Joshi et al., 2015; Rivilis et al., 2011). Such difficulties can also impact negatively on academic attainment (Harrowell, Hollén, Lingam & Emond, 2018), physical activity (Kwan, King-Dowling, Hay, Faught & Cairney, 2016) and quality of life (Zwicker, Harris & Klassen, 2013); leading to motor skill impairment being increasingly viewed as a public health concern (Bürgi et al, 2011; Robinson, Palmer & Bub, 2016). Recent research suggests that 12-17.4% of 4-6 year olds exhibit motor skills that are poor enough to be classified as 'probable' Developmental Coordination Disorder (DCD; Amador-Ruiz et al., 2018; De Milander, Coetzee & Venter, A, 2016).

Consequently, substantial efforts have been directed towards identifying interventional approaches that are effective at remediating motor skill deficits in children (Preston et al., 2016; Smits-Engelsman et al., 2018; Yu, Sit & Burnett, 2018). However, a major limiting factor in delivering such interventions is the focus often on traditional, highly resource-intensive models of service provision. For example, many interventions are only accessible via referral to occupational or physical therapy services, and are designed for delivery by highly trained staff, in one-to-one sessions during a finite series of clinic/home visits. In many countries, including the United Kingdom, such services are increasingly pressured by staff shortages (Health Education England, 2017; Lin, Zhang & Dixon, 2015) and struggle to meet waiting-time targets (Information Services Division Scotland, 2018). Meanwhile, parents report dissatisfaction with the level and timeliness of support provided (Novak, Lingam, Coad & Emond, 2012; Pentland et al., 2016; Soriano, Hill & Crane, 2015).

Searching for a creative solution, there has been some experimentation with embedding occupational therapists (OTs) within classrooms (e.g. Missiuna et al. 2017), to build closer collaboration across health and education services, and facilitate more rapid identification and diagnosis than traditional wait-listing procedures enable. This raises the question of whether similarly innovative inter-disciplinary approaches to treatment delivery might also be beneficial. Embedding motor skill interventions within schools has a number of potential advantages - such as integrating interventions into the routine of the school curriculum to create more sustained and frequently-dosed treatment regimens, these being important factors in moderating the effectiveness of motor-skill interventions (Yu et al., 2018). Such an approach may also enhance sharing of best-practice across health *and* education professionals, enabling more tiered approaches to providing treatment and thus expediting access (Camden, Wilson, Kirby, Sugden & Missiuna, 2015). Lastly, it is reasonable to believe many teachers would be highly motivated collaborators in such initiatives, given the importance of motor skills in the context of academic development (Cameron, Cottone, Murrah, & Grissmer, 2016; Giles et al., 2018).

The current paper therefore aims to describe the evidence base for school-based motor skill interventions. A systematic review of the findings from existing studies has yet to be conducted, so there is a benefit in determining the relative quality and strength of evidence for different approaches and identifying common principles that influence efficacy. This review also provides an opportunity to respond to calls for greater evaluation of motor skill interventions' effectiveness *in ecologically valid contexts* (Blank et al., 2019), something examining school-based interventions may help to emphasise. With this in mind this review also adopted the World Health Organisation's (WHO) International Classification of Functioning, Disability and Health (ICF) Model (WHO, 2013) as a framework for evaluating the impact of interventions. This model, amongst other useful insights, suggests interventions should be evaluated in terms of their success not only at improving impairment in 'body function and structure' (i.e. supporting the development of specific motor skills) but also in reducing associated activity and participation limitations and negative effects on factors relating to wellbeing (e.g. mental health). Such a multifactorial approach to evaluating intervention efficacy is necessary to inform the interdisciplinary models of service provision that are emerging in many countries (e.g. Hutton & Soan, 2017; Wilson & Harris, 2018).

METHODS

Inclusion Criteria

The inclusion criteria were developed using PICOS criteria (Liberati et al., 2009), with studies included if: (1) a 3 to 12 years old *Population* was sampled (reflecting pre- to primary/elementary school age) that had no diagnosed neurological disorders impairing muscle function (e.g. cerebral palsy); (2) the *Intervention* implemented the practise of motor skills exclusively in a school/classroom setting; (3) the study included a *Control* group that was of comparable motor competence to the intervention group; (4) the *Outcome* included at least one objective measure of motor-skill (which we defined as the primary outcome) that was not a specific athletic/sporting skill; (5) the *Study design* was a randomised controlled or case-controlled (i.e. not fully randomised) trial.

Electronic search strategy and Information sources

A search strategy (reported in Appendix 1) was developed by combining search terms describing the PICOS criteria to identify potentially relevant studies in five electronic databases: AMED, Medline, PsycINFO, Cochrane and CINAHL. If conference abstracts were identified, the reviewers searched for the corresponding full texts.

Study selection

Eligibility was independently assessed through title and abstract screening by four reviewers (LE, MW, EB and AC) in a standardised, unblinded manner: LE and MW screened all abstracts from January 2012 up to October 2017, with a 5% crossover implemented to assess agreement. A computer-based random number generator (https://www.random.org/) selected the articles included in this crossover. Once all abstracts were screened, the same process was implemented for full-text screening. EB and AC replicated this process for articles published between October 2017- August 2018, under the supervision of LE and MW. The inter-rater agreement was 100% in both phases of review, so arbitration was not necessary.

Data extraction process

Using a modified version of the Cochrane Data Extraction form (Higgins & Green, 2011) LE, MW, EB and AC undertook data extraction, with each independently reviewing half the data extraction forms in each phase (i.e. at least two reviewers reviewed each article's data extraction). Suspected duplicates were explored further by examining author lists, sample sizes, outcomes and findings. Information was extracted on both primary (i.e. objective measures of motor skills) and secondary outcomes measures, which were defined as any additional assessments of changes in participants' activity and/or participation relating to activities of daily living, mental health or wellbeing .

Risk of bias in individual studies

For studies published prior to October 2017, risk of bias (RoB) was assessed independently by LE and MW using the Cochrane Risk of Bias Tool (Higgins et al., 2011) and then compared across these two assessors. EB and AC replicated this same process for later studies. For each study the proportion (out of seven) of criteria rated as 'low-risk' was calculated to give an indication of the overall level of risk within a given study (high percentage indicates lower risk). Effect sizes were calculated using Cohen's *d*.

RESULTS

Electronic searches initially identified a total of 22,368 studies, one further article was identified via a conference abstract and three articles were added manually after being identified through selected articles' reference lists. Figure 1 illustrates the review process that refined this initial search down to the 23 included studies, whose key descriptive characteristics are summarised in Table 1. All included studies involved some form of motor skills training program, with most either specifically targeting children's Fundamental Movement Skills (FMS) (n = 12) or handwriting (n = 7). In line with recent clinical practice recommendations (Blank et al., 2019), handwriting programs were classified as targeting activity-level limitations in function, whilst the remaining FMS, Fine- and Global-motor programs were classified as targeting 'body and structure function' level impairment, with respect to the ICF model (WHO, 2013).

{Insert Figure 1 here}

{Insert Table 1 here}

Risk of Bias

Figure 2 shows the results of the RoB assessments, which indicated the reporting of methods was poor (e.g. insufficient detail to evaluate risk of bias in 51% of all judgements). Only two studies (Case-Smith et al., 2014a; Case-Smith et al., 2014b) provided sufficient information about the study design to allow a judgement on all seven potential RoBs. Categorically 'high-risk' practices were most frequently observed in relation to: randomising and blinding participants to the condition allocation (17%), attrition bias (17%) and selective outcome reporting (25%). Appendix 2 details RoB judgements by individual study.

{Insert Figure 2 here}

Population

The included studies involved 2590 participants, with sample sizes ranging from 23 to 274 children (*M*= 112.61, *SD*= 75.57, Median = 93, IQR= 84.5). Ten studies provided further information about the specific demographics of their sample, with three sampling only children with some form of motor-deficit or delay. Notably though, two of these studies categorically excluded children with additional learning difficulties/developmental disorders (Chang & Yu, 2014; Wilson et al., 2016). Meanwhile, Bardid et al. (2013) did not include additional information about co-occurring difficulties within their sample. This is despite the acknowledged rarity of "pure" developmental motor disorders (Blank et al., 2019). Five studies sampled populations with low socioeconomic status (SES; Bellows et al., 2013; Brian et al., 2017; Foulkes et al., 2017; Hamilton & Liu, 2017; Johnstone, Hughes, Janssen & Rilley, 2017), and one included participants with both low SES and motor deficits (Africa & van Deventer, 2017). Additionally, one study sampled a group of pre-school children with a variety of intellectual and developmental disabilities[1], treating them collectively as a single category (Favazza et al., 2013).

[1] Defined as: Developmental disability, Autism, communication disorder, intellectual disability & "other"

Intervention categorisation

To aid meaningful comparisons across studies, type-of-intervention was grouped by category of motor skill it primarily sought to develop, leading to four categories: (i) *Fundamental Movement Skill (FMS) Interventions*, training Object-manipulation (e.g. throwing), locomotion (e.g. running) and/or balance (e.g. hopping) skills. FMS is a class of motoric activity previously defined as 'building block skills' that underpin the capacity to perform more context-specific motor actions (Logan, Ross, Chee, Stodden & Robinson, 2018); (ii) *Fine Motor Skill Interventions*, exclusively practising small movements of the hand, fingers, wrists, toes and feet, and commonly featuring reach-to-grasp movements or tapping activities; (iii) *Handwriting Interventions*, where participants practise pen or digital-stylus strokes relevant to letter formation; (iv) *Global Motor Skill Interventions*, encompassing a diverse range of both fine- (e.g. connecting dots) and gross- (e.g. kicking a ball) motor skill activities, with the purported intention of eliciting generalised benefits in motor competence.

Outcome categorisation

The breadth of assessment methods used to measure changes in motor skill across studies presented challenges for synthesis, with only five assessments used across more than one study. These were the: Test of Gross Motor Development 2nd Edition (TGMD-2; Ulrich, 2000, n=9); Peabody Developmental Motor Scale 2nd Edition (PDMS-2, Folio & Fewell, 2000; n=3); Bruininks-Osteresky Test of Motor Proficiency 2nd Edition (BOT-2, Bruininks & Bruininks, 2005, n=3); Beery-Buktenica Developmental Test of Visual-Motor Integration (DTVMI, Beery & Beery, 2004, n=3) and Evaluation Tool of Children's Handwriting-Manuscript (ETCH-M, Amundson, 1995, n=2). Consequently, the primary outcome measures extracted were thematically classified into seven categories (summarised in Table 2) to facilitate comparison between studies using different outcomes that were still theoretically consistent in measuring the same underlying construct. All but two of these categories (Handwriting Legibility and Speed) measured changes at the level of 'body function and structure', as defined by the ICF model (WHO, 2013). Some studies did include further secondary outcomes assessing 'activity and participation'. These were: physical activity levels (Bellows et al., 2013; Chow et al., 2016; Johnstone, et al., 2017) or engagement in Activities of Daily Living (ADL) (Axford et al., 2013; Favazza et al, 2013).

{Insert Table 2 here}

Fundamental Movement Skills (FMS) Interventions

Of the studies investigating FMS interventions, all but two reporting significant benefits at post-test (see Table 3). RoB was variable across studies (0-57%) but in the two studies with the greatest proportions of low risk criteria (>50%), significant benefits were reported (Bardid et al., 2013; Brian et al., 2017).

{Insert Table 3 here}

{Insert Figure 3 here}

Object-manipulation skills were the most frequently examined outcome - with significant benefit in this domain reported in 9/10 studies (Altunsoz & Goodway, 2016; Bardid et al., 2013; Bellows et al., 2013; Bellows et al., 2017; Brian et al., 2017; Donath, Faude, Hagmann, Roth & Zahner, 2015; Favazza et al., 2013; Johnstone et al., 2017; Rajović, Berić, Bratić, Živković & Stojiljković, 2016). Significant benefits were also observed in 4/6 studies assessing effects on gross-motor skills (Bardid et al., 2013; Bellows et al., 2013; Hamilton & Liu, 2017; Johnstone et al., 2017). One study reported significant improvements in VMI and global motor ability (Hamilton & Liu, 2017), and another reported significant improvements in several measures of manual dexterity (Rajović et al., 2016).

For 22 outcomes, across 7/12 FMS studies, sufficient data were reported to calculate effect size (ES) estimates with confidence intervals. Summarising this evidence (Figure 3): for half these outcomes a ‘large’ effect size (>.8) was reported and for 17 outcomes (77%) positive results were likely replicable (i.e. lower bound for ES > 0). Where outcomes of a similar type were used in multiple studies, the evidence generally indicated there was some degree of positive benefit on measures of Object-manipulation, with only one of the five relevant studies potentially reflecting a type 1 error (Johnstone et al., 2017). However, evidence for benefits to Gross Motor control were more mixed, with confidence intervals crossing zero for three of six ES's. Three studies in this group (Bardid et al., 2013; Chow, Leis, Humbert, Muhajarine & Engler-Stringer, 2016; Hamilton, & Liu, 2017) used exactly the same outcome (Gross Motor Quotient on the TGMD-2), with the one study that failed to find a reliable effect differing from the others in terms of its sample size (smaller) and sample characteristics (not sampling either children with motor delay or from a low SES background).

Four FMS papers also measured outcomes related to activity and/or participation. Three utilised accelerometers or pedometers to measure physical activity (PA) (Bellows et al., 2013; Chow et al., 2016; Johnstone et al., 2017), whilst Favazza et al. (2013) measured ADL from teacher-reports. Significant improvements were found at post-test in both studies measuring moderate-to-vigorous-physical-activity (Chow et al., 2016; Johnstone et al., 2017). Counts per minute were also found to significantly increase following intervention in Johnstone et al. (2017) but not Chow et al. (2016). No other PA outcomes were improved following intervention. Gross-motor ADLs were found to improve following the Favazza et al (2013) intervention, but fine-motor ADLs were unaffected.

All FMS interventions focused on a 4-6 year old age range and tended to examine effects in typically developing children. Only two studies specifically looked at benefits within children with motor delays or developmental disorders (Bardid et al., 2013; Favazza et al., 2013), although these were amongst those reporting the largest ESs (Figure 3). Total dosage (in hours) for FMS interventions varied greatly from 6 to 40 hours but no consistent patterns were apparent. For example, the two most sustained interventions (Chow, et al., 2016; Johnstone et al., 2017) returned some of the smallest effect sizes (Figure 3). Teachers were tasked with intervention implementation in six studies and significant benefits were observed in all but one of these (Chow et al., 2016).

Fine-Motor Skills Interventions

Only two studies (Axford, Joosten & Harris, 2018; Ohl et al., 2013) evaluated interventions designed to develop fine-motor control (see Table 4). These sampled typically developing children aged 5-6 years, implemented interventions of approximately equal duration (9-10 weeks) but differed in implementation strategy (teacher-led technology vs. multi-disciplinary team) and intensity (150 vs. 30 minutes). In both studies RoB was high, with fewer than 50% of design aspects in either study judged as ‘low’ risk.

A variety of outcomes were used across the studies (describable as measuring VMI, Manual Dexterity and Handwriting; as defined in Table 2), with inconsistent results. Ohl et al. (2013) found significant improvement at post-test for VMI and manual dexterity (measured by the BOT-2) but not for pen grip, whilst Axford et al. (2018) report no benefits to VMI but improvements in drawing (motor-coordination subtest of the DTVMI). Axford et al (2018) also implemented the Shore Handwriting Screen (Shore, 2003), with only one of its five outcomes (copying capital letters) significantly improving following intervention. Regarding activity and participation outcomes, Axford et al. (2018) also mention measuring outcomes related to ADLs but did not provide information on statistical differences across groups. Across both studies several results were not reported in sufficient detail to calculate effect size estimates. Where such calculations were possible (Figure 4) variability in these estimates raise doubts as to their potential replicability (i.e. lower bounds for ES were all < 0).

{Insert Table 4 here}

{Insert Figure 4 here}

Handwriting Interventions

Seven studies targeted handwriting ability and whilst all reported some evidence of significant improvements in handwriting (Table 5), results were mixed with respect to specific outcome. All but one of these studies, which worked with a younger (Kindergarten) age group (Donica, 2015), sampled typically developing children between 5-7 years old.

Five interventions were delivered by teachers, either independently or in collaboration with a consulting OT, all of which reported some form of significant functional improvements in the ‘activity’ of Handwriting. This included: legibility (Case-Smith et al., 2014a & 2014b; Donica et al., 2015; Roberts, Derkach-Ferguson, Siever & Rose, 2014), writing fluency (Case-Smith et al., 2014a;

Case-Smith et al., 2014b), letter formation (Roberts et al., 2014), paragraph copying (Wolf, Abbott & Berninger, 2017) and writing speed (Case Smith et al., 2014a). Two of these studies, involving OT collaboration, had the lowest RoB (57% and 71% of criterion judged 'low') amongst all selected studies (Case-Smith et al., 2014a & 2014b). Donica et al.'s (2015) study, which worked with a younger age group, over a much longer duration (104 weeks), reported significant improvement in overall legibility. These results are partly corroborated by another study (Roberts, Derkach-Ferguson, Siever & Rose, 2014) that used the same intervention ("Handwriting Without Tears") over 9 weeks, without OT support, and found improvements on the Minnesota Handwriting Assessment which assesses letter legibility, form, alignment, size and spacing (Reissman, 1999).

Two studies did not provide enough information to calculate effect sizes (Chang & Yu, 2014; Roberts et al., 2014) and within the other studies sufficient information on non-significant results was often not provided. Effect sizes (ESs) for legibility outcomes (Figure 5) on the 'Ramzor' (Lifshitz & Har-Zvi, 2015) and 'Slingerland' interventions (Wolf et al., 2017) were medium-to-large, whereas for the 'Write Start' (Case-Smith et al., 2014a; Case-Smith et al., 2014b) and the 'Handwriting Without Tears' interventions (Donica et al, 2015) average ES varied from low-to-high, to the extent that null-effects in the population could not be ruled out. ES estimates for handwriting speed and fluency were reported for the 'Write Start' intervention (Case-Smith et al., 2014a; Case-Smith et al., 2014b), with significant benefits to lowercase speed potentially unreliable but more robust (small-to-medium sized) effects for writing fluency.

{Insert Table 5 here}

{Insert Figure 5 here}

Global-Motor Skills Interventions

Two studies implemented interventions that were intended to provide general improvements in motor skills (see Table 6). These varied greatly in their sample characteristics and in the intensity and duration of their interventions. Both studies had fewer than 50% of the criteria on which RoB was rated as ‘low’. Wilson et al. (2016) evaluated both a mental imagery and perceptuo-motor training intervention and found primary outcomes to be improved by both, in a group of 7-12 year olds with coordination difficulties. However, they did not provide sufficient additional information to calculate effect sizes. Meanwhile, Africa and van Deventer (2017) report that outcomes such as VMI and gross-motor ability did not significantly improve in 5-6 year olds with poor initial VMI scores following an intervention that trained both these abilities. With only Africa and van Deventer providing sufficient information to calculate effect sizes and reporting null-results, further exploration of ES estimates was unnecessary. The limited information available on this type of intervention cautions against over-interpreting the few positive findings discussed here.

{Insert Table 6 here}

DISCUSSION

The present review aimed to study the efficacy of motor skills interventions implemented in school settings. Nineteen (83%) of 23 identified reported significant benefits on at least one aspect of motor skill. A variety of motor skill domains were improved via a number of different interventional approaches, including fully inclusive and potentially less stigmatising whole-class approaches (Kennedy et al., 2018), as well as more targeted interventions for children with recognised motor difficulties. Whilst the majority of these interventions were teacher-led, the use of technology such as iPads for motor skill instruction (Axford et al., 2018; Chang & Yu, 2014), and more interdisciplinary methods were also trialled (Case-Smith et al., 2014a, Case-Smith et al., 2014b; Donica, 2015; Ohl et al., 2013). Such novel methods hold potential promise for widening access to support for children with motor difficulties, via the provision of more resource-efficient, and collaborative models of delivery (Hutton & Soan, 2017; Wilson & Harris, 2018).

The prevalence of interventions designed to take one of two specific theoretical approaches was also notable. These approaches were: (i) a ‘task-orientated’ approach focused on improving particular functional motor abilities such as handwriting (Miyahara, Hillier, Pridham & Nakagawa, 2017); (ii) an approach focussed on training foundational movement patterns that are proposed as building blocks for more contextually-specific motor abilities (Logan et al., 2018). In comparison, far fewer interventions adopted more 'processes-orientated' approaches purporting to act on underlying sensorimotor mechanisms (e.g. visuo-motor integration), which hope to yield more systemic benefits that generalise to all motor abilities. This perhaps reflects the influence of previous systematic reviews that concluded task-orientated motor skill interventions yield greater benefits in children with DCD (Preston et al., 2016; Smits-Engelsman et al., 2013).

It should be noted that biases were present in many of the reviewed interventions' methodologies, which need to be acknowledged when reviewing the evidence from effect size summaries (Figures 3-5). This analysis suggests that many significant findings potentially reflected type-1 errors, indicating possible publication bias - a concern highlighted in previous motor-skill intervention reviews (Yu et al., 2018). Considering only the most robust evidence, there does still appear to be reasonably consistent evidence of one specific handwriting intervention generating moderate benefits in writing fluency but not legibility (Case-Smith et al, 2014a; Case-Smith et al., 2014b) and FMS interventions having a small-to-moderate benefit on measures of Object-manipulation (4/5 studies: Bardid et al, 2013; Bellows et al., 2017; Favazza et al., 2013; Rajović et al., 2016). More methodologically rigorous studies are needed though to corroborate the existence of benefits, and then better quantify their size.

Interventions almost exclusively focussed on improving basic motor function (e.g. Fundamental Movement Skills), with the only notable exceptions being interventions focused on handwriting activity. Similarly, assessment tools used in the reviewed studies primarily sought to measure improvements at the level of 'body function and structure', which is perhaps logical but limiting given the narrow aim of most interventions. Outside handwriting, only a few studies looked at how motor skill interventions impacted on other aspects of activity and participation (such as physical activity levels and ADLs). No interventions looked at the impact of motor skill interventions on factors such as a child's mental health, wellbeing or educational attainment, despite the well documented relationships between motor ability and these factors (Blank et al., 2019).

Limitations

Several specific limitations in the literature on school-based interventions were revealed. First, articles frequently failed to report information on study methodology, key to evaluating studies' RoB. Methodological weaknesses in relation to blinding and randomisation were also common. Second, outcome-measures lacked consistency, even within studies evaluating interventions hypothesised to improve the same motor-skill (e.g. handwriting), making synthesis of results challenging. Future research programmes should strive for greater uniformity and standardisation in selecting outcome-measures. For example, only one of the articles (Wilson et al., 2016) assessed changes in performance using the standardised Movement Assessment Battery for Children (MABC-2), which is the only assessment battery currently widely recommended for measuring clinically relevant motor deficits (Blank et al., 2019). Better reporting of statistical results to aid calculation and pooling of effect sizes for inclusion in a meta-analysis is also needed in the future. A substantial proportion (33.3%) of studies failed to supply any information, and several others provided only partial information (16.7%).

This review did not restrict itself to investigating interventions in clinical samples per se but did include five studies where children were identified as having some form of motor-deficit or delay (Africa & Deventer, 2015; Bardid et al., 2013; Chang & Yu, 2014; Favazza et al., 2013; Wilson et al., 2016). Such deficits rarely exist without co-occurring features such as attention deficits, conduct problems, and emotional difficulties (Green & Baird, 2005). Yet these studies either failed to report on or excluded cases with co-occurring difficulties. Future studies would be better advised to select more representative samples and factor consideration of co-occurring difficulties into their analyses (Blank et al., 2019).

Moreover, less than a quarter (5/23) studies (Bellows et al., 2017; Case-Smith et al., 2014a & 2014b; Foulkes et al., 2017; Roberts et al., 2014) included any further follow-up beyond the immediate post-test assessments. Whilst time and resource-expensive, and potentially subject to high attrition rates, extended follow-up is essential to establishing the long-term efficacy of interventions.

Lastly, beyond the academically important skill of handwriting very few studies assessed impacts at the level of activity and participation, as defined by the ICF model (WHO, 2013). Whilst establishing whether basic motor function is improved might be a valuable 'first step' in the development of some interventions, future research would benefit from trialling more multifaceted interventions that focus on more than one level of the ICF Model (WHO, 2013). In particular, measuring wider impacts on activity, participation, mental-health and wellbeing is important. One potential strength of a school-based approach is its ability to delineate important activity and participation situations, and thereby ensure that an intervention has the best possible chance of improving meaningful outcomes for a child.

Conclusions

This was the first systematic review of studies that have trialled school-based motor skill interventions. The review finds evidence in favour of the efficacy of school-based interventions, as a novel mode of delivery, in almost all of the studies reviewed. Issues with the quality of reporting and methodologies mean caution is required when interpreting individual studies' results though. More methodologically robust studies are needed, with more heterogeneous samples, which explore directly what factors moderate an intervention's efficacy. Lastly, future work would benefit from considering a wider range of outcomes, and the ICF model should be used to guide such approaches.

<u>KEY MESSAGES</u>

- 83% of studies that trialled a school-based intervention reported statistically significant improvements in children's objectively measured motor skills, suggesting they may have values as a means of improving support for children with motor difficulties
- Additional 'risk-of-bias' assessment and effect size analyses suggest these positive findings need to be interpreted with caution
- Current research frequently does not acknowledge outcomes wider than direct effects on motor skill. How interventions influence outcomes beyond "body structure and function" should be considered

- Future research into motor-skill intervention (school-based or otherwise) would benefit from more standardisation in outcome measures
- More research is needed into school-based motor skill interventions to ascertain appropriate dosage, intensity and the relative efficacy of universal vs. targeted interventions

REFERENCES

Africa, E. K., & van Deventer, K. J. (2017). A motor-skills programme to enhance visual motor integration of selected pre-school learners. *Early Child Development and Care, 187*(12), 1960-1970. doi.org/10.1080/03004430.2016.1201478

Altunsöz, I. H., & Goodway, J. D. (2016). Skiping to motor competence: the influence of project successful kinesthetic instruction for preschoolers on motor competence of disadvantaged preschoolers. *Physical Education and Sport Pedagogy*, *21*(4), 366-385. doi.org/10.1080/17408989.2015.1017453

Amador-Ruiz, S., Gutierrez, D., Martínez-Vizcaíno, V., Gulías-González, R., Pardo-Guijarro, M. J., & Sánchez-López, M. (2018). Motor Competence Levels and Prevalence of Developmental Coordination Disorder in Spanish Children: The MOVI-KIDS Study. *Journal of School Health*, *88*(7), 538-546. doi.org/10.1111/josh.12639

Amundson, S. J. (1995). *Evaluation Tool of Children's Handwriting*. Homer, AK: O.T. Kids, Inc.

Axford, C., Joosten, A, V., & Harris, C. (2018). iPad applications that required a range of motor skills promoted motor coordination in children commencing primary school. *Australian Occupational Therapy Journal, 65*(2), 146-155. doi.org/10.1111/1440-1630.12450

Bardid, F., Deconinck, F. J., Descamps, S., Verhoeven, L., De Pooter, G., Lenoir, M., & D'Hondt, E. (2013). The effectiveness of a fundamental motor skill intervention in pre-schoolers with motor problems depends on gender but not environmental context. *Research in Developmental Disabilities*, *34*(12), 4571-4581. doi.org/10.1016/j.ridd.2013.09.035

Barnett, A. L., Hill, E. L., Kirby, A., & Sugden, D. A. (2015). Adaptation and Extension of the European Recommendations (EACD) on Developmental Coordination Disorder (DCD) for the UK context. *Physical & Occupational Therapy in Pediatrics*, *35*(2), 103-115. doi.org/10.3109/01942638.2014.957430.

Beery, K. E., & Beery, N. A. (2004). *The Beery-Buktenica Developmental Test of Visual-Motor Integration: Administration, scoring, and teaching manual* (5th ed.). Minneapolis, MN: NCS Pearson.

Bellows, L. L., Davies, P. L., Anderson, J., & Kennedy, C. (2013). Effectiveness of a physical activity intervention for Head Start preschoolers: A randomized intervention study. *American Journal of Occupational Therapy*, *67*(1), 28-36. doi.org/10.5014/ajot.2013.005777

Bellows, L. L., Davies, P. L., Courtney, J. B., Gavin, W. J., Johnson, S. L. & Boles, R. E. (2017). Motor skill development in low-income, at-risk preschoolers: A community-based longitudinal intervention study. *Journal of Science and Medicine in Sport, 20*, 997-1002. doi.org/10.1016/j.jsams.2017.04.003

Berninger, V. W. (2007). *PAL-II: Process Assessment of the Learner: Diagnostic Assessment for Reading and Writing. Administration and Scoring Manual for Reading and Writing*. Pearson.

Bhatia, P., Davis, A. & Shamas-Brandt, E. (2015). Educational gymnastics: The effectiveness of Montessori practical life activities in developing fine motor skills in kindergartners. *Early Education and Development, 26*, 594-607. doi.org/10.1080/10409289.2015.995454

Blank, R., Smits-Engelsman, B., Polatajko, H., & Wilson, P. (2012). European academy for childhood disability (EACD): Recommendations on the definition, diagnosis and intervention of developmental coordination disorder (long version)*. *Developmental Medicine & Child Neurology*. *54*(1), 54-93. doi.org/10.1111/j.1469-8749.2011.04171.x

Blank, R., Barnett, A. L., Cairney, J., Green, D., Kirby, A., Polatajko, H., ... & Vinçon, S. (2019). International clinical practice recommendations on the definition, diagnosis, assessment, intervention, and psychosocial aspects of developmental coordination disorder. *Developmental Medicine & Child Neurology*, 61(3), 242-285. doi.org/10.1111/dmcn.14132

Brian, A., Goodway, J. D., Logan, J. A., & Sutherland, S. (2017). SKIPing with Head Start teachers: Influence of T-SKIP on object-control skills. *Research Quarterly for Exercise and Sport, 88*(4), 479-491. doi.org/10.1080/02701367.2017.1375077

Bruininks, R. H., & Bruininks, B. D. (2005). *The Bruininks-Oseretsky test of motor proficiency, 2nd edition: Manual.* Circle Pines, MN: AGS Publishing.

Bürgi, F., Meyer, U., Granacher, U., Schindler, C., Marques-VIdal, P., Kriemler, S., & Puder, J. J. (2011). Relationship of physical activity with motor skills, aerobic fitness and body fat in preschool children: a cross-sectional and longitudinal study (Ballabeina). *International Journal of Obesity*, *35*(7), 937-944. doi.org/10.1038/ijo.2011.54

Camden, C., Wilson, B., Kirby, A., Sugden, D., & Missiuna, C. (2015). Best practice principles for management of children with developmental coordination disorder (DCD): results of a scoping review. *Child: Care, Health and Development*, *41*(1), 147-159. doi.org/10.1111/cch.12128

Cameron, C. E., Cottone, E. A., Murrah, W. M., & Grissmer, D. W. (2016). How are motor skills linked to children's school performance and academic achievement?. *Child Development Perspectives*, *10*(2), 93-98. doi.org/10.1111/cdep.12168

Case-Smith, J., Holland, T., & White, S. (2014). Effectiveness of a co-taught handwriting program for first grade students. *Physical & Occupational Therapy in Pediatrics, 34*(1), 30-43. doi.org/10.3109/01942638.2013.783898

Case-Smith, J., Weaver, L., & Holland, T. (2014). Effects of a classroom-embedded occupational therapist–teacher handwriting program for first-grade students. *American Journal of Occupational Therapy*, *68*(6), 690-698. doi.org/10.5014/ajot.2014.011585

Chang, S. H., & Yu, N. Y. (2014). The effect of computer-assisted therapeutic practice for children with handwriting deficit: A comparison with the effect of the traditional sensorimotor approach. *Research in Developmental Disabilities*, *35*(7), 1648-1657. doi.org/10.1016/j.ridd.2014.03.024

Chow, A. F., Leis, A., Humbert, L., Muhajarine, N., & Engler-Stringer, R. (2016). Healthy Start–Départ Santé: A pilot study of a multilevel intervention to increase physical activity, fundamental movement skills and healthy eating in rural childcare centres. *Canadian Journal of Public Health*, *107*(3), 312-318. doi.org/10.17269/cjph.107.5279

De Milander, M., Coetzee, F. F., & Venter, A. (2016). Prevalence and effect of developmental coordination disorder on learning-related skills of South African grade one children. *South African Journal for Research in Sport, Physical Education and Recreation*, *38*(2), 49-62.

Donath, L., Faude, O., Hagmann, S., Roth, R., & Zahner, L. (2015). Fundamental movement skills in preschoolers: A randomized controlled trial targeting object control proficiency. *Child: Care, Health and Development*, *41*(6), 1179-1187. doi.org/10.1111/cch.12232

Donica, D. K. (2015). Handwriting Without Tears (®): General education effectiveness through a consultative approach. *The American Journal of Occupational Therapy*, *69*(6), 690-698. doi.org/10.5014/ajot.2015.018366

Erez, N., & Parush, S. (1999). The Hebrew handwriting evaluation. *School of Occupational Therapy. Faculty of Medicine. Hebrew University of Jerusalem, Israel*.

Favazza, P. C., Siperstein, G. N., Zeisel, S. A., Odom, S. L., Sideris, J. H., & Moskowitz, A. L. (2013). Young athletes program: Impact on motor development. *Adapted Physical Activity Quarterly*, *30*(3), 235-253. doi.org/10.1123/apaq.30.3.235

Folio, M., & Fewell, R. F. (2000). *Peabody Developmental Motor Scales – Second Edition*. Austin: Pro-ed.

Foulkes, J. D., Knowles, Z., Fairclough, S. J., Stratton, G., O'Dwyer, M., Ridgers, N. D., & Foweather, L. (2017). Effect of a 6-week active play intervention on fundamental movement skill competence of preschool children: A cluster randomized controlled trial. *Perceptual and Motor Skills*, *124*(2), 393-412. doi.org/10.1177/0031512516685200

Giles, O. T., Shire, K. A., Hill, L. J., Mushtaq, F., Waterman, A., Holt, R. J., Culmer, P. R., Williams, J. H. G., Wilkie, R. M., & Mon-Williams, M. (2018). Hitting the target: mathematical attainment in children is related to interceptive-timing ability. *Psychological science, 29(*8), 1334-1345. doi.org/10.1177/0956797618772502

Green D, Baird G. DCD and overlapping conditions. In Sugden D, Chambers M, editors. *Children with Developmental Coordination Disorder*. London, UK: Whurr Publications, 2005: 93–118

Hamilton, M., & Liu, T. (2017). The effects of an intervention on the gross and fine motor skills of Hispanic pre-K children from low SES backgrounds. *Early Childhood Education Journal*, 1-8. doi.org/10.1007/s10643-017-0845-y

Harrowell, I., Hollén, L., Lingam, R., & Emond, A. (2018). The impact of developmental coordination disorder on educational achievement in secondary school. *Research in Developmental Disabilities*, *72*, 13-22. doi.org/10.1016/j.ridd.2017.10.014

Health Education England (2017). *An Investigation into the Occupational Therapy Workforce in London.* https://www.rcot.co.uk/news/new-report

Henderson, S. E., Sugden, D. A., & Barnett, A. L. (2007). *Movement Assessment Battery for Children*, Second Edition, London: Pearson.

Higgins & Green, (2011). *Cochrane Handbook for Systematic Reviews of Interventions*. Retrieved from: http://handbook.cochrane.org/.

Higgins, J. P., Altman, D. G., Gøtzsche, P. C., Jüni, P., Moher, D., Oxman, A. D., Savović, J., Schulz, K. F., Weeks, L., & Sterne, J. A. (2011). The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *British Medical Journal*, *343*, d5928. doi.org/10.1136/bmj.d5928

Hung, L., Chang, Y,. W., Chen, S. F., Chen, C . S., & Lee, Y. D. (2003) [Elementary read/write test]. Taipei, Taiwan: Psychological Co.

Hutton, E., & Soan, S. (2017). Lessons learned from introducing universal strategies designed to support the motor and functional skills of Reception and Year 1 children in a sample of primary schools in South East England. *Education 3-13*, *45*(1), 83-103. doi.org/10.1080/03004279.2015.1048270

Information Services Division Scotland (2018). *Allied Health Professionals – Musculoskeletal Waiting Times in NHS Scotland.* https://www.isdscotland.org/Health-Topics/Waiting-Times/Publications/2018-06-19/2018-06-19-AHPMSK-Summary.pdf

Johnstone, A., Hughes, A. R., Janssen, X., & Reilly, J. J. (2017). Pragmatic evaluation of the Go2Play Active Play intervention on physical activity and fundamental movement skills in children. *Preventive Medicine Reports, 7*, 58–63. doi.org/10.1016/j.pmedr.2017.05.002

Joshi, D., Missiuna, C., Hanna, S., Hay, J., Faught, B. E., & Cairney, J. (2015). Relationship between BMI, waist circumference, physical activity and probable developmental coordination disorder over time. *Human Movement Science*, *40*, 237-247. doi.org/10.1016/j.humov.2014.12.011

Kennedy, J., Missiuna, C., Pollock, N., Wu, S., Yost, J., & Campbell, W. (2018). A scoping review to explore how universal design for learning is described and implemented by rehabilitation health professionals in school settings. *Child: Care, Health and Development*. doi.org/10.1111/cch.12576

Kwan, M. Y., King-Dowling, S., Hay, J. A., Faught, B. E., & Cairney, J. (2016). Longitudinal examination of objectively-measured physical activity and sedentary time among children with and without significant movement impairments. *Human Movement Science*, *47*, 159-165. doi.org/10.1016/j.humov.2016.03.004

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P., ... & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *PLoS medicine*, *6*(7), e1000100. doi.org/10.1371/journal.pmed.1000100

Lifshitz, N., & Har-Zvi, S. (2015). A comparison between students who receive and who do not receive a writing readiness interventions on handwriting quality, speed and positive reactions. *Early Childhood Education Journal, 43*(1), 47–55. doi.org/10.1007/s10643-013-0629-y

Lin, V., Zhang, X., & Dixon, P. (2015). Occupational therapy workforce in the United States: Forecasting nationwide shortages. *PM&R*, *7*(9), 946-954. doi.org/10.1016/j.pmrj.2015.02.012.

Lingam, R., Jongmans, M. J., Ellis, M., Hunt, L. P., Golding, J., & Emond, A. (2012). Mental health difficulties in children with developmental coordination disorder. *Pediatrics*, *129*(4), e882-91. doi.org/10.1542/peds.2011-1556

Logan, S. W., Ross, S. M., Chee, K., Stodden, D. F., & Robinson, L. E. (2018). Fundamental motor skills: A systematic review of terminology. *Journal of sports sciences*, *36*(7), 781-796. doi.org/10.1080/02640414.2017.1340660

McGrew, K. S., Woodcock, R. W. (2001). Technical manual. Woodcock-Johnson III. Itasca, IL: Riverside

De Milander, M., Coetzee, F. F., & Venter, A. (2016). Teachers' ability to identify children with developmental coordination disorder. *African Journal for Physical Activity and Health Sciences*, *22*(4: 1), 990-1005.

Milone, M. (2007). *Test of Handwriting Skills revised manual*. Novato, CA: Academic Therapy Publications

Missiuna, C., Pollock, N., Campbell, W., DeCola, C., Hecimovich, C., Sahagian Whalen, S., ... & McCauley, D. (2017). Using an innovative model of service delivery to identify children who are struggling in school. *British Journal of Occupational Therapy*, *80*(3), 145-154. doi.org/10.1177/0308022616679852

Miyahara, M., Hillier, S. L., Pridham, L., & Nakagawa, S. (2017). Task-oriented interventions for children with developmental co-ordination disorder. *The Cochrane Database of Systematic Reviews*, *7*, CD010914. doi.org/0.1002/14651858.CD010914.pub2.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G & The PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med 6*(6): e1000097. doi.org/10.1371/journal.pmed.1000097

Novak, C., Lingam, R., Coad, J., & Emond, A. (2012). ‘Providing more scaffolding’: parenting a child with developmental co-ordination disorder, a hidden disability. *Child: Care, Health and Development*, *38*(6), 829-835. doi.org/10.1111/j.1365-2214.2011.01302.x.

Ohl, A. M., Graze, H., Weber, K., Kenny, S., Salvatore, C., & Wagreich, S. (2013). Effectiveness of a 10-week tier-1 response to intervention program in improving fine motor and visual-motor skills in general education kindergarten students. *American Journal of Occupational Therapy, 67*(5), 507–514. doi.org/10.5014/ajot.2013.008110

Pentland, J., Maciver, D., Owen, C., Forsyth, K., Irvine, L., Walsh, M., & Crowe, M. (2016). Services for children with developmental co-ordination disorder: an evaluation against best practice principles. *Disability and Rehabilitation*, *38*(3), 299-306. doi.org/10.3109/09638288.2015.1037464

Preston, N., Magallón, S., Hill, L. J., Andrews, E., Ahern, S. M., & Mon-Williams, M. (2017). A systematic review of high quality randomized controlled trials investigating motor skill programmes for children with developmental coordination disorder. *Clinical Rehabilitation*, *31*(7), 857-870. doi.org/10.1177/0269215516661014

Rajović, R., Berić, D., Bratić, M., Živković, M., & Stojiljković, N. (2016). Effects of an “NTC” exercise program on the development of motor skills in preschool children. *Physical Education and Sport*, *14*(3), 315-329. doi.org/10.22190/FUPES1603315R

Reisman, J. (1999). *Minnesota Handwriting Assessment*. Psychological Corporation.

Rivilis, I., Hay, J., Cairney, J., Klentrou, P., Liu, J., & Faught, B. E. (2011). Physical activity and fitness in children with developmental coordination disorder: a systematic review. *Research in developmental disabilities*, *32*(3), 894-910. doi.org/10.1016/j.ridd.2011.01.017

Roberts, G., Derkach-Ferguson, A., Siever, J. & Rose, M. (2014). An examination of the effectiveness of Handwriting Without Tears(R) instruction. *Canadian Journal of Occupational Therapy, 81*, 102-13. doi.org/10.1177/0008417414527065

Robinson, L. E., Palmer, K. K., & Bub, K. L. (2016). Effect of the children's health activity Motor Program on Motor skills and self-regulation in head start Preschoolers: An efficacy Trial. *Frontiers in Public Health*, *4*, 173. doi.org/10.3389/fpubh.2016.00173

Schneck, C. M., & Henderson, A. (1990). Descriptive analysis of the developmental progression of grip position for pencil and crayon control in nondysfunctional children. *American Journal of Occupational Therapy*, *44*(10), 893-900. doi.org/10.5014/ajot.44.10.893

Shore, L. (2003). Shore handwriting screening for early handwriting development: Examiner's manual. Chaska, MN: Harcourt Assessment, Inc.

Smits-Engelsman, B. C., Blank, R., van der Kaay, A. C. C., Mosterd-van der Meijs, R., Vlugt-van den Brand, E., Polatajko, H. J., & Wilson, P. H. (2013). Efficacy of interventions to improve motor performance in children with developmental coordination disorder: a combined systematic review and meta-analysis. *Developmental Medicine and Child Neurology*, *55*(3), 229-237. doi.org/10.1111/dmcn.12008

Smits-Engelsman, B., Vinçon, S., Blank, R., Quadrado, V. H., Polatajko, H., & Wilson, P. H. (2018). Evaluating the evidence for motor-based interventions in developmental coordination disorder: A systematic review and meta-analysis. *Research in Developmental Disabilities*, *74*, 72-102. doi.org/10.1016/j.ridd.2018.01.002

Soriano, C. A., Hill, E. L., & Crane, L. (2015). Surveying parental experiences of receiving a diagnosis of developmental coordination disorder (DCD). *Research in Developmental Disabilities*, *43*, 11-20. doi.org/10.1016/j.ridd.2015.06.001.

Sparrow, S.S., Cicchetti, D.V., & Baila, D.A. (2005). *Vineland II: A revision of the vineland adaptive behavior scales: I. Survey/caregiverform* (2nd ed.). Circle Pines, Minnesota: American Guidance Service.

Ulrich, D. A. (2000). *Test of Gross Motor Development* (2nd ed.), Austin, TX.

Wilson, A. L., & Harris, S. R. (2018). Collaborative occupational therapy: Teachers' impressions of the Partnering for Change (P4C) model. *Physical & Occupational Therapy in Pediatrics*, *38*(2), 130-142. doi.org/10.1080/01942638.2017.1297988

Wilson, P. H., Adams, I. L. J., Caeyenberghs, K., Thomas, P., Smits-Engelsman, B., & Steenbergen, B. (2016). Motor imagery training enhances motor skill in children with DCD: A replication study. *Research in Developmental Disabilities, 57*, 54–62. doi.org/10.1016/j.ridd.2016.06.014

Wolf, B., Abbott, R. D. & Berninger, V. W. (2017). Effective beginning handwriting instruction: Multi-modal, consistent format for 2 years, and linked to spelling and composing. *Reading and Writing, 30*, 299-317. doi.org/10.1007/s11145-016-9674-4

World Health Organization. (2013). *How to use the ICF: A practical manual for using the International Classification of Functioning, Disability and Health (ICF). Exposure draft for comment*, Geneva: WHO

Yu, J. J., Sit, C. H. P., & Burnett, A. F. (2018). Motor skill interventions in children with Developmental Coordination Disorder: A systematic review and meta-analysis. *Archives of Physical Medicine and Rehabilitation*. doi.org/10.1016/j.apmr.2017.12.009

Zwicker, J. G., Harris, S. R., & Klassen, A. F. (2013). Quality of life domains affected in children with developmental coordination disorder: a systematic review. *Child: Care, Health and Development*, *39*(4), 562-580. doi.org/10.1111/j.1365-2214.2012.01379.x

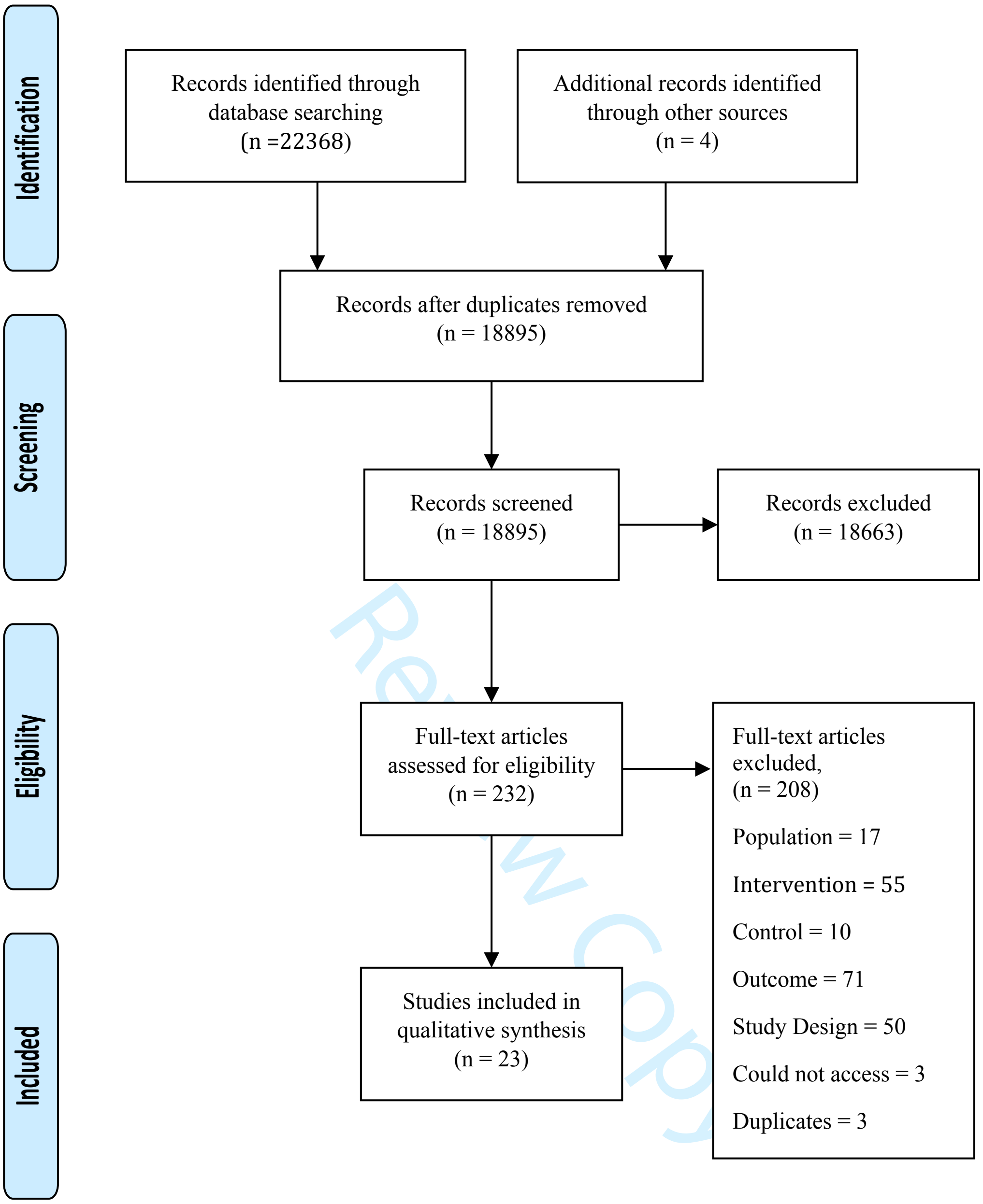

Figure 1- A PRISMA flow diagram (adapted from Moher, Liberati, Tezlaff, Altman, & the PRISMA group, 2009) illustrating the review process

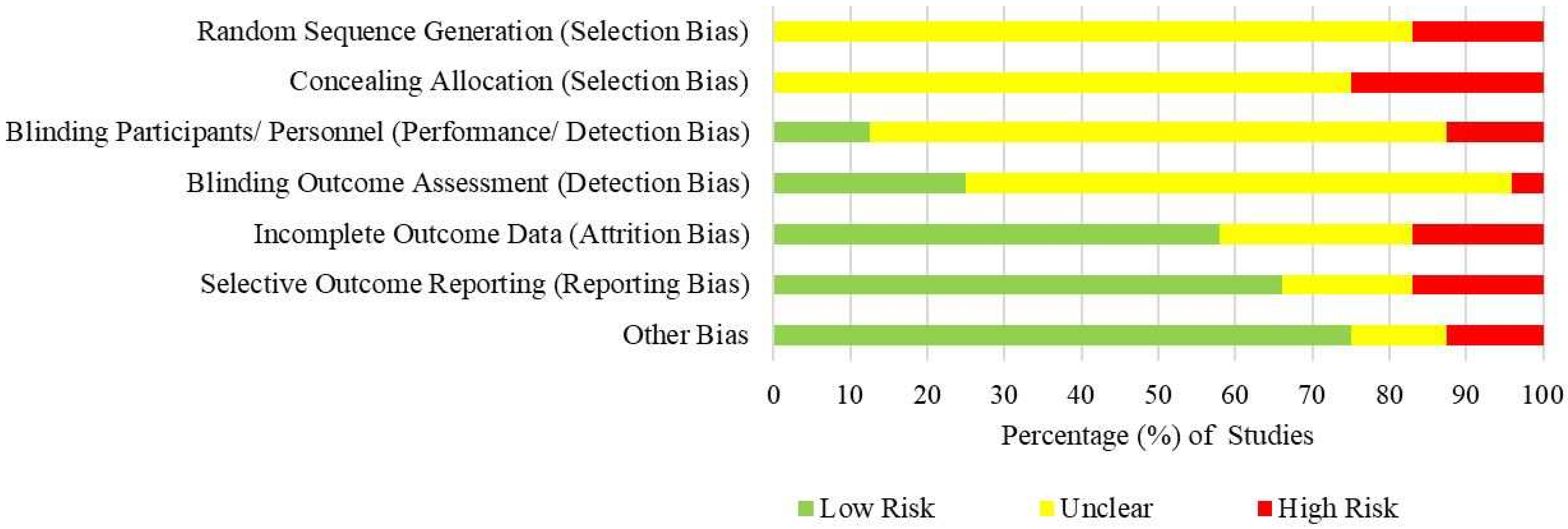

Figure 2: Summary of the risk of bias assessments across all criterion for the 23 included studies. NB: Other bias included multiple intervention groups analysed as one cohort.

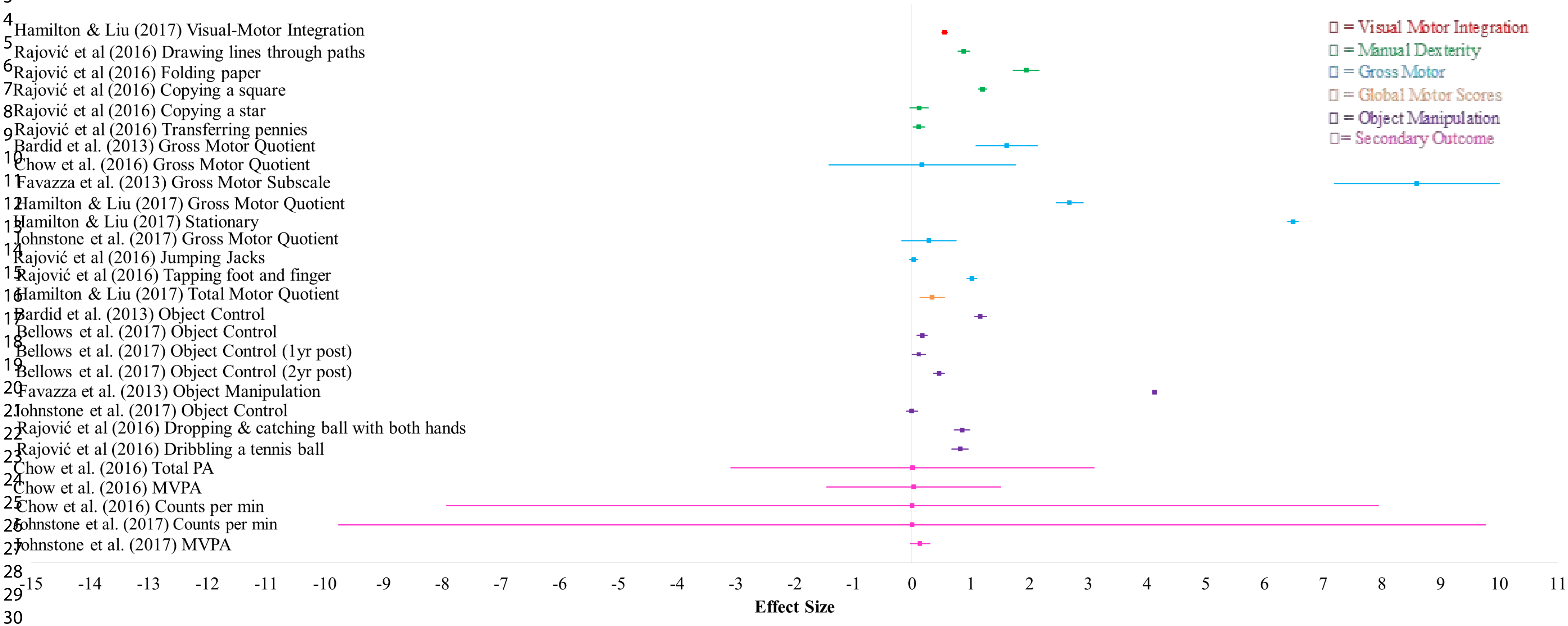

Figure 3- Effect size and confidence intervals by objective motor skills outcome measures for Fundamental Movement Skill (FMS) intervention studies.
NB: PA = Physical Activity, MVPA = Moderate to Vigorous Physical Activity.

1

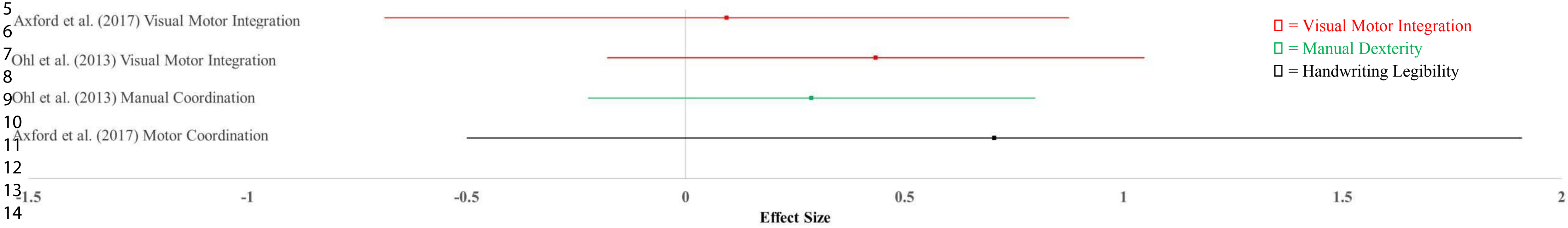

Figure 4 - Effect size and confidence intervals by objective motor skills outcome measures for Fine Motor Skill intervention studies

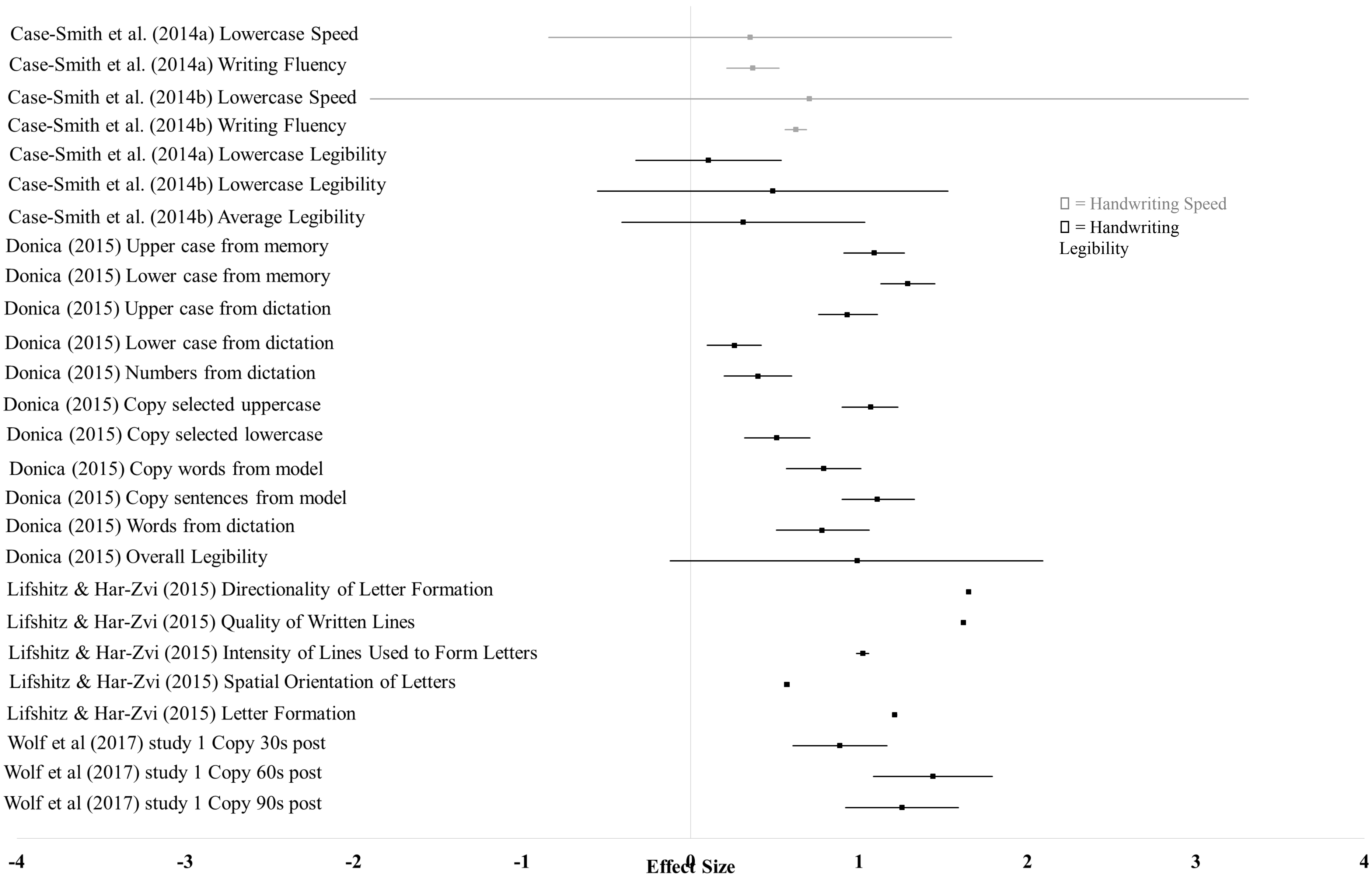

Figure 5 - Effect size and confidence intervals by objective motor skills outcome measures for Handwriting intervention studies

Table 1

Descriptive summary of included studies characteristics by intervention-type

		Fine Motor (n=2)	Fundamental Movement Skills (n=12)	Handwriting (n=7)	Global Motor (n=2)	Total (n=23)
Design of Intervention (%)	RCT	50	78	33	50	48
	Case-Controlled	50	22	66	50	52
Who Implemented the Intervention (%)	Teacher	50	56	29	50	46
	Researcher	-	11	14	50	19
	Multidisciplinary Team	50	-	43	-	23
	Outside Provider	-	33	-	-	8
	Technology	-	-	14	-	4
Risk of Bias (%)	Low	36	29	39	35	34
	High	14	14	14	-	12
	Unclear	50	57	47	65	54
Mean Intervention Length [*SD*] (Weeks)		9.50 [0.71]	15.77 [11.63]	26.14 [35.04]	9.5 [6.36]	17.1 [20.76]
Mean Intervention Duration [*SD*] (Hours)		16.25 [12.37]	17.79 [11.01]	41 [62.84]	13 [11.31]	50.93 [82.12]
Mean Number of Participants [*SD*]		83.50 [41.72]	147.33 [83.82]	79.71 [36.34]	32.5 [13.44]	95.89 [71.99]

Table 2

Thematic categorisation of assessments used as primary outcomes of objective motor skills

Outcome Types	Description
Global Motor Ability [B]	Outcomes measures representing an overall score for motor ability, calculated from combining results on several sub-tests of different types of motor skill (e.g. fine and gross), as in the Movement Assessment Battery for Children (Henderson, Sugden & Barnett, 2007) overall battery score.
Gross Motor [B]	Outcome measures exclusively measure the capacity to control movement of large muscle groups (e.g. legs and arms) to perform activities such as jumping-jacks, running.
Object Manipulation [B]	Outcome measures specifically evaluating interactions with objects in the immediate environment (e.g. throwing and catching) that were not focused on extensive fine-motor, in-hand manipulations of said objects.
Visual Motor Integration (VMI) [B]	Outcomes measures of the extent which an individual can integrate visual and motor abilities to perform eye-hand coordinated tasks: *specifically* measured by the Beery-Buktenica Developmental Test of Visual-Motor Integration (Beery & Beery, 2004)
Manual Dexterity [B]	Outcome measures which required manipulation of the hand and fingers to complete tasks that were not canonically defined as handwriting. This category included activities such as folding paper, and non-writing pen-skills.
Handwriting Legibility [A]	Handwriting outcome measures that assessed transcription -related handwriting skills, including letter formation and copying activities. Assessments used to assess this group of outcomes included the Hebrew Handwriting Readiness Assessment (Erez & Parush, 1999).
Handwriting Speed [A]	Handwriting outcome measures that assessed the speed at which participants form letters and words. Assessments used to generate these outcomes included the Evaluation Tool of Children's Handwriting–Manuscript (Amundson, 1995).

Notes: [A]= Activity & Participation outcomes, [B]= Body Funtion & Structure outcomes (ICF model, WHO, 2013)

Table 3. *Summary of Fundamental Movement Skills (FMS) intervention studies*

Study	***Participants***	***N***	***Intervention (Implementer)***	***Intervention Length (est. number of hrs)***	***Outcome measures***	***Risk of Bias Rating (% Low Risk)***
Altunsoz & Goodway (2015)	3-5-year olds	72	SKIP (Trained outside provider- motor skill instructor)	8 weeks (8 hours)	**TGMD-2** - Object Control** [B]	29
Bardid et al. (2013)	3-5-year olds at risk of motor delay	93	Intervention based on locomotor, ball, jumping, posture & balance, play, rhythm & dance skills (Teacher)	10 weeks (20 hours)	**TGMD-2** - Gross Motor Quotient** [B] - Object Control** [B]	57
Bellows et al. (2017)	3-5-year olds	250	Food Friends Fun (Mighty Move & New Foods) (Teacher)	18 Weeks (24 hours)	**BOT-2** - Object Control (post-test)** [B] - Object Control (1yr post)** [B] - Object Control (2yrs post)** [B]	43
Bellows et al. (2013)	3-5-year olds from low SES	274	Intervention consisting of various stability, locomotor & manipulation activities (Teacher)	18 weeks (24 hours)	**PDMS-2** - Gross Motor Quotient** [B] - Object Manipulation** [B] **Physical Activity (pedometer)** - Total Step Count [A] - Weekend Step Count [A] - Weekday Step Count [A]	0
Brian et al. (2017)	Children from low SES with mean age of 4.7 years (*SD*=2.4)	122	T-SKIP (Teacher)	8 weeks (7.5 hours)	**TGMD-2** - Object Control** [B]	57
Chow et al. (2016)	3-5-year olds	69	Fundamental movement skill practice (Teacher)	48 weeks (Not specified)	**TGMD-2** - Gross Motor Quotient [B] **Physical Activity (accelerometer)** - Counts per min [A] - MVPA* [A] - Total physical activity [A]	43
Donath et al. (2015)	3-5-year olds	57	Intervention consisting of object control skills (Trained outside provider- exercise instructor)	6 weeks (Not specified)	**TGMD-2** - Object Control* [B]	29
Favazza et al. (2013)	3-5-year olds with developmental disorders	233	Young Athletes (Teacher)	8 weeks (12 hours)	**PDMS-2** - Object Manipulation** [B] **VTRF** - Gross motor* [A] - Fine motor [A]	14

Foulkes et al. (2017)	3-5-year olds from low SES	162	Active Play (Trained outside provider – active play practiitoners)	6 weeks (6 hours)	**TGMD-2** - Object Control [B] - Gross Motor Quotient [B]	14
Hamilton & Liu (2017)	Children from low SES, mean age 4.56 years (*SD* not specified)	149	Peabody Motor Activities Program (Researcher)	16 weeks (13 hours)	**PDMS-2** - VMI**[B] - Total Motor Quotient* [B] - Gross Motor Quotient** [B] - Fine Motor Quotient [B]	14
Johnstone et al. (2017)	Children from low SES with mean age of 7 years (*SD*= 1.1)	257	Fundamental movement skill practice; two intervention groups (Trained outside provider- play workers)	20 weeks (40 hours)	**TGMD-2** - Gross Motor Quotient** [B] - Object Control [B] (both intervention groups) **Physical Activity (accelerometer)** - Counts per min** [A] - MVPA** [A]	14
Rajović et al. (2016)	4-6-year olds	60	Nikola Tesla Centre physical exercise programme (not specified)	20 weeks (Not specified)	**BOT-2** - Drawing Lines Through Paths** [B] - Folding Paper** [B] - Copying a Square** [B] - Copying a Star [B] - Transferring Pennies [B] - Jumping Jacks [B] - Tapping Foot and Finger** [B] - Dropping and Catching** [B] - Dribbling** [B]	43

Notes: SKIP = Successful Kinesthetic Instruction for Preschoolers, T-SKIP = Teacher-implemented SKIP, TGMD-2 = Test of Gross Motor Development-2 (Ulrich, 2000), PDMS-2 = Peabody Developmental Motor Scales-2 (Folio & Fewell (2000), VMI = Visual Motor Integration; VTRF = Vineland Adaptive Behaviour Scale (Sparrow, Cicchetti & Baila, 2005), * p<.05, ** p<.01; [A]= Activity & Participation outcomes, [B]= Body Funtion & Structure outcomes (ICF model, WHO, 2013)

Table 4. *Summary of Fine Motor Skill Intervention studies*

Study	***Participants***	***N***	***Intervention (Provider)***	***Intervention Length (est. number of hrs)***	***Outcome measures***	***Risk of Bias Rating (% Low Risk)***
Axford et al. (2018)	5-6-year olds	54	22 different fine motor skill iPad applications (Teacher)	9 weeks (22.5 hours)	**DTVMI** - VMI [B] - motor coordination* [B] **SHS** - Capitals** [A] - On the line [A] - Sizing [A] - Position [A] - Orientation [A]	29
Ohl et al. (2013)	Children with mean age of 5.19 years (*SD* = 0.34)	113	STEPS-K (Multi-disciplinary team- teachers and OTs)	10 weeks (5 hours)	**DTVMI** - VMI** [B] **BOT-2** - Manual Coordination* [B] **Developmental Scale of Pencil & Crayon Grips** - Pen grip [A]	43

Notes: STEPS-K= Specialised Teaching and Enhancement of Performance Skills for Kindergarteners, DTVMI = Developmental Test of Motor Integration (Beery, Beery & Buktenica, 2004), SHS = Shore Handwriting Screen (Shore, 200), BOT-2 = Bruininks-Oseretsky Test of Motor Proficiency Second Edition (Bruininks, 2005), Developmental Scale of Pencil & Crayon Grips (Schneck & Henderson, 1990); * p<.05 ** = p<.01; [A]= Activity & Participation outcomes, [B]= Body Funtion & Structure outcomes (ICF model, WHO, 2013)

Table 5. *Summary of Handwriting intervention studies*

Study	***Participants***	***N***	***Intervention (Provider)***	***Intervention Length (est. number of hrs)***	***Outcome measures***	***Risk of Bias Rating (% Low Risk)***
Case-Smith et al. (2014a)	"First-graders" (~6-8 years)	139	"Write Start" (Multi-disciplinary team – teacher, intervention specialist and OT)	12 weeks (18 hours)	**ETCH-M** - Lowercase Legibility** [A] - Lowercase Speed* [A] **WJ-III** - Writing Fluency** [A]	71
Case-Smith et al. (2014b)	5-7-year olds	67	"Write Start" (Multi-disciplinary team – teacher and OT)	12 weeks (16 hours)	**ETCH-M** - Lowercase Legibility* [A] - Lowercase Speed [A] - Average Legibility [A] **WJ-III** - Writing Fluency* [A]	57
Chang & Yu (2014)	6-8-year old children with dysgraphic symptoms	42	Two interventions: Computer Assisted Handwriting Training Programme & Sensorimotor Handwriting Training Programme (Technology)	6 weeks (9 hours)	**E R/W T** - Total handwriting score* [A] - Mean pause time [A] - Mean pen grip [A] - Mean peak velocity* [A]	29
Donica (2015)	Kindergarten (~4 years)	93	Handwriting Without Tears; 2 groups (Multi-disciplinary team – teachers, teaching assistants and OT)	104 weeks (47.5hours)	**THS-R** - Overall legibility** [A] - Uppercase from memory** [A] - Lowercase from memory** [A] - Uppercase from dictation'** [A] - Lowercase from dictation [A] - Numbers from dictation [A] - Copy selected Uppercase ** [A] - Copy selected Lowercase [A] - Copy words from model * [A] - Copy sentences from model ** [A] - Words from dictation * [A]	14
Lifshitz & Har-Zvi (2015)	Children with mean age of 5.39 years (*SD*= 0.45)	101	Ramzor Handwriting Programme (Researcher)	12 weeks (4 hours)	**HHRA** - Directionality** [A] - Line Quality** [A] - Line Intensity** [A] - Spatial Orientation** [A] - Letter Formation** [A] - Writing on the line [A] - Name Writing [A]	14

					- Letter spacing [A] - Word spacing [A] - Pencil Grip [A] - Non-dominant Hand [A] - Handwriting Speed [A]	
Roberts et al. (2014)	Children with average age of 6.2 years (*SD* not specified)	83	Handwriting Without Tears (Teacher)	9 weeks (13 hours)	**MHA** - Total test score* [B]	43
Wolf et al. (2017)	"First graders" (~ 6-7 years)	33	Slingerland handwriting instruction (Teacher)	28 weeks (105 hours)	**PAL-IIe** - Paragraph copying (30s)* [A] - Paragraph copying (60s)* [A] - Paragraph copying (90s)* [A]	43

Notes: ETCH-M = Evaluation Tool of Children's Handwriting–Manuscript (Amundson, 1995); WJ-III = Woodcock-Johnson Tests of Cognitive Abilities-III (McGrew, Schrank, & Woodcock); THS-R = Test of Handwriting Skills – Revised (Milone, 2007); E R/W T = Elementary Read/Write Test (Hung, Chang, Chen, Chen, & Lee, 2003); HHRA = Hebrew Handwriting Readiness Assessment, (Erez & Parush, 1999); MHA = Minnesota Handwriting Assessment (Reissman, 1999), PAL-II = Process Assessment of the Learner, 2nd Edition, (Berninger, 2007); * p<.05 ** p<.01; [A]= Activity & Participation outcomes, [B]= Body Funtion & Structure outcomes (ICF model, WHO, 2013)

Table 6. *Summary of Global Motor Skills intervention studies*

Study	***Participants***	***N***	***Intervention (Provider)***	***Intervention Length (est. number of hrs)***	***Outcome measures***	***Risk of Bias Rating (% Low Risk)***
Africa & van Deventer (2017)	5-6 from low SES schools with low VMI skills	23	VMI & gross motor skill training (Teacher)	14 weeks (21 hours)	**DTVMI** - Visual motor skills [B] - motor coordination [B] - visual perception [B]	29
Wilson et al. (2016)	7-12-year olds with motor coordination difficulties	42	Two intervention groups: Imagery training & perceptual motor training (Researcher)	5 weeks (5 hours)	**MABC-2** - Total Impairment Score* [B] (both intervention groups)	43

Notes: DTVMI = Developmental Test of Visual Motor Integration (Beery, Buktenica, & Beery, 2010), TGMD-2 = Test of Gross Motor Development-2 (Ulrich, 2000); Flag Posting Test (Bhatia, Davis & Shamas-Brandt, 2015); MABC = Movement-ABC 2nd Edition (Henderson, Sugden & Barnett, 2007); * p<.05 ** p<.01; [A]= Activity & Participation outcomes, [B]= Body Funtion & Structure outcomes (ICF model, WHO, 2013)

APPENDIX 1

Table of Search Terms

Population	**Intervention**	**Setting**	**Outcome**
Child*	Physical therap*	School-based	Fine motor
Infant*	Occupational therap*	School based	Gross motor
School child*	Intervention*	Educational program*	Balance
Adolescen*	Treat*	Co-taught	Posture
Preschool	Rehab*	School*	Motor coordination
Pre-school	Therap*	Teacher*	Handwriting
Boy*	Program*	Teacher-led	Motor performance
Girl*	Physiotherapy	Co-teach*	Movement
Young people	Sensory integration	Classroom*	Occupational performance
	Neuro-developmental treatment	Educator*	Clumsiness
	Neurodevelopmental treatment	Lesson*	Functional
	NDT		Activity
	Neuromotor task training		Motor impairment
	Neuro-motor task training		Motor abilit*
	NTT		Motor control
	Cognitive orientation to daily occupational performance		Motor function
	CO-OP		Motor learning
	Perceptual-motor training		Dysgraphia
	Motor imagery training		Motor development
	Sensory integration training		Motor dysfunction
	Task-specific training		Motor skill*
	Task specific training		Visual-motor
	Timing control		Visuomotor
	Kinaesthetic training		Legibility
	Motor training		Play skill*
	Gross motor		Visual motor
	Motor coordination		Functional performance

	Motor skill*		Mobility function*
	Movement skill*		Eye-hand coordination
	Manual coordination		Hand-eye coordination
	Locomotor skill*		In-hand manipulation
	Handwriting		Grasp strength
	Fine motor		Grip strength
			Mobility
			Visuo-motor

APPENDIX 2

Risk of Bias for Individual Studies

Citation	Random Sequence Generation	Concealing Allocation	Blinding of Participants / Personnel	Blinding of Outcome Assessment	Incomplete Outcome Data	Selective Outcome Reporting	Other Bias
Africa & van Deventer (2017)	?	?	?	?	+	?	+
Altunsoz & Goodway (2016)	?	?	?	?	+	?	+
Axford et al. (2018)	?	-	?	?	+	?	+
Bardid et al. (2013)	?	?	+	?	+	+	+
Bellows et al. (2013)	?	-	-	-	-	-	?
Bellows et al. (2017)	-	?	?	?	+	+	+
Brian et al. (2017)	?	?	?	+	+	+	+
Case-Smith et al. (2014a)	-	-	+	+	+	+	+
Case-Smith et al. (2014b)	-	-	-	+	+	+	+
Chang &Yu (2014)	?	?	?	?	?	+	+
Chow et al. (2016)	?	?	?	?	+	+	+

Donath et al. (2015)	?	?	?	?	?	+	+
Donica (2015)	?	?	?	?	?	+	-
Favazza et al. (2013)	?	?	?	?	+	?	?
Foulkes et al. (2017)	?	-	-	+	-	-	-
Hamilton & Liu (2017)	?	?	?	?	+	-	?
Johnstone et al. (2017)	-	?	?	?	-	+	-
Lifshitz & Har-Zvi (2015)	?	?	?	?	?	-	+
Ohl et al. (2013)	?	?	?	+	-	+	+
Rajovic et al. (2016)	?	?	?	?	+	+	+
Roberts et al. (2014)	?	?	+	?	?	+	+
Wilson et al. (2016)	?	?	?	+	?	+	+
Wolf et al. (2017)	?	?	?	?	+	+	+