Meta-analyses and narrative review of home-based interventions to improve literacy and mathematics outcomes for children between the ages of 3 and 5 years old

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Abstract

The purpose of these meta-analyses were to examine the effectiveness of home-based interventions aimed at improving literacy and mathematics outcomes for preschool aged children (mean age = 4.29; range = 3.07 to 5.32 years) and to develop an understanding of what home-based interventions work in different contexts. A total of 32 studies met the inclusion criteria for these meta-analyses; 30 studies included sufficient data for inclusion in the meta-analyses and 2 studies did not contain sufficient quantitative data and instead were summarised in a narrative review. The average weighted effect size for interventions with literacy (d = 0.10; CI = -0.17, 0.38; n = 27) and mathematical outcomes (d = 0.18; CI = -1.62, 1.99; n = 8) were minimal. Hence, these meta-analyses showed that home-based interventions had minimal effect on literacy and mathematical outcomes for pre-schoolers. There were more home-based interventions with literacy (N = 28) than mathematical outcomes (N = 10). The heterogeneity showed no variability indicating that all intervention impacted on children's outcomes to similar effect. Overall, many interventions were relatively light touch (i.e., time spent engaging in parent training) and the engagement requirement of the parent in some studies was minimal (e.g., reading a short text message). More in-depth research into the components of interventions (e.g., focus, training approaches) and evaluation of interventions before they are implemented is essential for ensuring that early interventions will be effective and lead to the development of the intended skills.

Keywords: Meta-analysis; home-based; numeracy; literacy; interventions; pre-schoolers

Introduction

There is increasing consensus by researchers and practitioners that children's experiences during the first five years of life influence many aspects of development and can have considerable, long-lasting effects throughout childhood, adolescence, and adulthood (Hoff, 2003; World Bank, 2015). Achievement in literacy and mathematics skills at preschool entry (i.e., broadly 3 to 5 years old; Duncan et al., 2007) predicts later educational attainment, employment, and health outcomes in adulthood (Entwisle et al., 2005; Morrisroe, 2014; OECD, 2013). However, approximately one third of children aged 3 to 4 years-old do not reach appropriate developmental milestones in literacy and numeracy across 72 countries worldwide (Sustainable Development Goals, 2019). Therefore, it is important to target interventions at this age group to avoid literacy and mathematical skills gaps from widening and children from falling developmentally behind in their literacy or mathematics skills (Cahoon et al., 2021; Sheridan et al., 2011). However, it is important to understand what mathematical and literacy interventions are most effective for improving early educational outcomes before executing an extensive and expensive intervention. Hence, this systematic review and meta-analyses aims to examine the effectiveness of home-based interventions aimed at improving literacy and mathematics outcomes for 3–5-year-olds and to develop an understanding of what home-based interventions work in different contexts.

Research indicates that early learning usually starts informally in the home when parents interact with their children (LeFevre et al., 2009; Niklas & Schneider, 2014; Skwarchuk et al., 2014). A predictive relationship between the quality of the home environment and educational outcomes has been long-established. Studies have found the quality of the home environment to be amongst the most important predictors of reading and mathematics achievement for children (Anders et al., 2012; Belsky et al., 2007; Melhuish et al., 2008; Skwarchuk et al., 2014). The quality of the home learning environment is often defined by the availability of educational resources (e.g., books and board games) used for engagement in reading and number play (Anders et al., 2012; Cankaya & LeFevre, 2016; Melhuish et al., 2008; Skwarchuk et al., 2014). The literature on the home learning environment also regularly focuses on frequency of engagement with numeracy and literacy activities, rather than the quality of interactions in this setting (Hornberg et al., 2021). Many parents engage their children in numerical activities such as counting, an activity involved in the Home Mathematics Environment (HME) and literacy activities such as reading, an activity utilised in the Home Literacy Environment (HLE) to prepare their children for school (Duncan et al., 2007; Sénéchal & LeFevre, 2002).

The Home Literacy Environment

Research demonstrates that home literacy activities are associated with children's literacy and language skills (Sénéchal & LeFevre, 2002, 2014). The HLE is generally defined as the activities that happen within the home that focus on learning literacy skills (Bracken & Fischel, 2008) and access to literacy resources (e.g., radio, storybooks; Inoue, Georgiou, Parrila & Kirby, 2018; Puglisi, Hulme, Hamilton & Snowling, 2017). The HLE also incorporates broader factors such as parents' literacy expectations and parental education (Dong et al., 2020). These interactions and attitudes are recognised as having broader impacts on the interconnected skills of language comprehension and vocabulary (Grolig, 2020).

The Home Literacy Model (Sénéchal & LeFevre, 2002) identifies two pathways of literacy learning in the home. The *formal* literacy experiences pathway was assessed through the frequency of parent involvement in literacy activities (e.g., reading and writing words) which predicted children's word reading. Whereas the *informal* literacy pathway was investigated through children's exposure to shared reading with parents and predicted children's vocabulary (developed by Sénéchal et al., 1996). Results from a meta-analysis including 59 studies indicates that the frequency of engagement with HLE activities has a positive, moderate impact on reading comprehension (z = .32). Specific components of the HLE have an effect on reading comprehension with parental beliefs, parental education and parental involvement in literacy activities having moderate effects (z = .32, z = .27, z = .30 respectively) and access to literacy resources having a weak effect on reading comprehension (z = .21; Dong et al., 2020). Overall, findings on the influence of the HLE support the Information Transfer Theory (Dearing et al., 2006) that suggests that parents transfer knowledge and skills associated with literacy via interactions in the home environment.

Joint storybook reading is a commonly reported HLE activity (Grolig, 2020). Although many studies capture the frequency of engaging in these activities through parent self-report questionnaires, joint storybook reading has also been rigorously assessed through observational methods. Roberts, Jergens and Burchinal (2005) tracked low-income African American children and their parents from 9 months to 4 years old and established that the amount of time spent engaging in shared book reading, or a child's enjoyment of the activity, was not predictive of child literacy skills. In contrast, maternal sensitivity during shared book reading and the use of recognised book reading strategies predicted child receptive vocabulary. The broader home environment as measured by the Home Observation Measurement of the Environment (HOME) tool was also identified as predicting receptive vocabulary and early literacy skills over and above the book reading observation measures, emphasising the importance of the general home environment for early development.

The Home Mathematics Environment

Kleemans and colleagues (2012) established that the frequency of engagement in parent–child numeracy activities and parents' numeracy expectations were unique predictors of early numeracy, even after controlling for child-level linguistic and cognitive factors. This emphasises the importance of home numeracy experiences on early numeracy skills development. Additionally, Huntsinger et al. (2016) found that participation in parent-child formal mathematics activities learned through explicit instruction (i.e., using rules, principles, and procedures e.g., calculations both addition and subtraction) were predictive of a child's mathematical knowledge. Skwarchuk and colleagues (2014) proposed a theoretical model of the Home Numeracy Environment, inspired by the Home Literacy Model (Sénéchal & LeFevre, 2002). Parent reported frequency of engagement in *formal* home numeracy practises (e.g., learning sums) accounted for unique variance in children's symbolic number knowledge whereas *informal* exposure to games with numerical content predicted children's non-symbolic arithmetic performance (Sénéchal & LeFevre, 2002). This hypothesised conceptual model of the home numeracy environment has been the basis for much research in the area (e.g., Jiménez Lira, 2016; Susperreguy et al., 2020; 2021).

Evidence regarding the relationship between frequency of home numeracy experiences and mathematics skills is not conclusive and several studies have failed to find a relationship (e.g., Leyva et al., 2017; Missall et al., 2015). A meta-analysis involving 51 quantitative studies found a small overall effect size for this relationship ($r = .13$, $SE = .03$, $p < .0001$; Daucourt et al., 2021).

In addition, a systematic review established an overall positive effect of the frequency of HME activities on mathematics skills, this was specifically true for those activities defined as developmentally “advanced” (e.g., basic arithmetic for 4-year-olds; Mutaf-Yildiz et al., 2020). Overall, these two reviews identify a significant correlation between frequency-based home numeracy environment (HNE) measures and children’s mathematical skills, providing evidence to support the importance of home-based mathematical learning. It is important to note that there is a vast amount of literature that examines the role of the HLE in comparison to the HNE (Burgess et al., 2002; Frijters et al., 2000; Kirby & Hogan, 2008; Sénéchal & LeFevre, 2002), perhaps reflecting parental beliefs that literacy activities were more vital than numeracy activities (Blevins-Knabe et al., 2000; Early et al., 2010). Nevertheless, there has been an increase in recent years investigating the role of the HME on later educational achievement (e.g., LeFevre et al., 2009; Hart et al., 2016; Sammons et al., 2015). An outstanding issue in this research is understanding the influence of the quality, rather than simply the frequency, of the interactions in the home environment (Hornburg et al., 2021). This could be addressed through investigating interventions that focus on changing parent/caregivers’ behaviour in the home.

Improving the home learning environment

Given the known correlation between the HLE and HNE and academic outcomes, a target for interventions could be to improve the home-based learning environment. The benefits of this focus could be two-fold. First, these studies could build evidence on the causal relationship between the home environment and children’s outcomes. Secondly, there is a lack of consensus on *how* to successfully intervene to improve home-based learning to benefit early outcomes. Thus, intervention studies could help identify successful strategies. Some researchers propose that intensive interventions are important (Sheldon & Epstein, 2005; Starkey & Klein, 2000), while others state that even non-intensive interventions can be effective, concluding that even with constrained budgets interventions should be undertaken (Niklas et al., 2016). Interventions may not have consistent findings across children from different demographic origins (Dodge, 2019). Therefore, individual differences should also be considered.

Given the focus of the current literature base, interventions could focus on either increasing the frequency of engagement with HLE/HME activities and/or improving the quality of the engagement with these learning events. More information is needed to distinguish *what* specific experiences these interventions should focus on (e.g., access the resources, parents' skills, or attitudes). A potential target may be the quality of parent-child interactions. For example, Bjorklund et al. (2004) examined the relationship between parental guidance and children's numeracy behaviour in a game context (e.g., chutes and ladders) and mathematics context (e.g., arithmetic problems) and found that parents provided varying levels of support and appropriately adjusted their behaviours to meet their child's abilities. However, parents' instructions (e.g., prompting or using cognitive directives, such as demonstrating a strategy) did not always lead to their children effectively using the identical strategy that the parent had displayed (e.g., single item counting, adding from one, adding from larger addends) in both contexts. This demonstrates that the influence of parent guidance is contingent on both children's abilities and the context in which numeracy is presented (Benigno & Ellis, 2004; Niklas et al., 2016).

There are some characteristics of an effective home environment that could be considered when developing interventions. For instance, in the domain of mathematics, the influence of parents' attitudes and beliefs about how children learn at home (Cahoon, Cassidy & Simms, 2017; LeFevre, Polyzoi, Skwarchuk, Fast, & Sowinski, 2010), parents' mathematical anxiety and its impact on child learning outcomes (e.g., Foley et al., 2017), and the beneficial role of mathematical language input (Purpura, Napoli, Wehrspann & Gold, 2017; Purpura et al., 2021). In addition, from the domain of literacy, evidence suggests that the nature of reading interactions is important. Specifically, studies have established that positive storybook reading interactions resulted in more frequent reading engagement and led to higher reading scores for children (Sonnenschein, Baker & Serpell., 2005; Sonnenschein & Munsterman, 2002).

Current review

It is important to understand what mathematical and literacy interventions are most effective for improving early educational outcomes. Especially in the context that researchers have identified that interventions targeting children's numeracy learning at home are lacking in comparison to literacy (Niklas et al., 2016; Starkey & Klein, 2000). Recent reports have emphasised the need for more systematic investigations of educational interventions to inform decisions about educational changes (Department for Education, 2017). Most reviews on intervention studies focus on those delivered in pre-school or school settings (e.g., Cheung & Slavin, 2013; Simms et al., 2017). This review will focus only on home-based interventions as the home environment is recognised as an important setting of early learning for children and a contributing factor in a child's educational outcomes (Lehrl et al., 2021b). The aim of this review is to obtain an understanding of what home-based literacy and mathematics interventions work in different contexts and why they are effective or ineffective for early educational outcomes. Focusing on interventions that employed randomised control trial methodology ensures that potential confounding variables, such as genetic inheritance or SES, is accounted for between experimental and control groups in individual studies (Kramer, 2016). Therefore, synthesising these types of studies enables conclusions to be drawn about the specific impact of home environment on outcomes, an important contrast to correlational studies that cannot account for these factors in this manner. This review will also provide systematic insight into the potential causal influence of the quality of the home environment on children's early learning outcomes.

Research questions

This systematic review will aim to answer the following questions:

1. Are there more robustly assessed literacy interventions than mathematical interventions?
2. What types of home-based literacy and mathematical interventions or programmes are most effective for improvements in early educational outcomes for children between the ages of 3 and 5?[1]
3. What are the demographics of the participants that take part in these interventions and are there individual differences that impact the efficacy of these interventions?
4. Identify the resource requirements (i.e., materials) of these interventions.

[1] *The order in which Question 1 and 2 are presented has been reversed from our pre-registered systematic review plan for ease of reporting.

Method

The purpose of this meta-analysis was to review mathematics and literacy interventions in the home for children between the ages of 3 and 5. All eligible studies were published between January 2000 to May 2020, this ensured that the materials included were relevant in terms of curriculum context, to the time of literature search conclusion. Full texts had to be available in English. This systematic review was preregistered on Open Science Framework (OSF, DOI 10.17605/OSF.IO/NM74Z). No ethical clearance was required for this study.

Literature Search

Ten literature databases and 7 unpublished grey literature databases were searched during this period. The 10 literature databases that were selected and searched were: (1) Education Resources Information Center (ERIC, platform ProQuest), (2) PsycINFO (platform ProQuest), (3) British Educational Index (platform EBSCO), (4) Social Sciences Citation Index (platform Web of Science), (5) International Bibliography of the Social Sciences (platform ProQuest), (6) Applied Social Sciences Index and Abstracts (platform ProQuest), (7) Cochrane Central Register of Controlled Trials (platform Cochrane Library), (8) Education Abstracts (platform EBSCO), (9) Academic Search Complete (platform EBSCO) and, (10) MEDLINE (platform ProQuest). The 7 unpublished grey literature databases included: (1) ProQuest Dissertations and Thesis, (2) Conference Proceedings Citation Index, (3) Websites of charitable and funding organisations (i.e. Nuffield Foundation, National Numeracy Trust, the Education Endowment Foundation and National Science Foundation (USA)), (4) Government departments (e.g. Department of Education), (5) World Health Organisation trials website and clinicaltrials.gov, (6) Google and Google Scholar (e.g. first 150 hits recorded, exact URL and date of access recorded) and, (7) OpenGrey. The pre-registered protocol had intended to also use Dissertation Abstract International. However, it was discovered that all content previously contained in this database had been moved to ProQuest Dissertation & Theses Global and that Dissertation Abstracts International was no longer available. **[Blinded]** University has no access to Dissertation Abstracts International and therefore this database was excluded at this time.

Each database was searched independently with the following comprehensive search terms: (child* OR kindergarten OR preschool* OR "early years*" OR parent* OR guardian OR "care giver" OR "3 year old*" OR "4 year old*" OR "5 year old*" OR teach* OR learn* OR instruct* OR train* OR program*) AND ("early num*" OR "math* intervention" OR "num* environment" OR "math* language intervention" OR "num* skills" OR math* OR num* OR "early literacy*" OR read* OR "reading intervention" OR "literacy intervention" OR "literacy skills" OR "storybook intervention" OR vocabulary) AND ("school readiness" OR "educational achievement" OR "educational outcomes" OR "developmental milestones") AND (home* OR "intervention study" OR random* OR "control trial" OR "control group" OR RCT OR "home based intervention" OR "early intervention" OR pre-test OR post-test OR "pre assessment" OR "post assessment" OR Quasi OR experimental).

Inclusion and Exclusion Criteria

To be included in the present meta-analyses each study had to meet the following criteria:

1. The study design must be a randomised control trial, this includes cluster randomised controlled trials, or quasi-randomised designs. Studies must include a comparison control condition (e.g., no intervention, practice-as-usual, waiting list, or active control

group). Matched subject or group designs, cross-over designs, single-subject designs and/or correlational designs are excluded.

2. Studies were included if the study involved children between the ages of 3-5 and their parents. If a study included a broader age range encompassing 3-5-year-old children, the first author and/or corresponding author was contacted to investigate if it was possible for data to be extracted for only the targeted age groups. Children must not be attending formal education (e.g., mainstream primary/elementary-level school) as this study aims to understand the effects of a home-based intervention.
3. Studies were excluded if the children were exclusively diagnosed with learning difficulties or developmental disorders. Interventions aimed at children screened or suspected of developmental disorders were also excluded.
4. Studies were included if they involved interventions aimed at improving mathematics (e.g., additional resources, practicing counting, recall of numbers etc.) and/or literacy (e.g., additional resources, letter recall etc.) skills. The intervention had to be carried out at home or aimed at parents and requiring parent participation. Delivery methods included those delivered by researchers, parents, early years practitioners or other trained professionals such as those who work for programs (e.g., Head Start). Interventions that include cognitive training (i.e., studies aimed at enhancing general cognition, not literacy and mathematical skills) were excluded.
5. The primary outcomes had to be mathematics and literacy ability, as measured by standardised tests of mathematics (e.g., British Ability Scale, Early Number Concepts) and/or standardised tests for literacy (e.g., Dynamic Indicators of Basic Early Literacy Skills) and/or cognitive experimental measures of specific mathematics and literacy

skills (e.g., speeded recall of arithmetic facts, flexible strategy use etc.). Secondary outcomes included: 1) attitudes towards learning mathematics and literacy for both parents and children and 2) parents understanding the appropriate level of learning for their children for that age group.

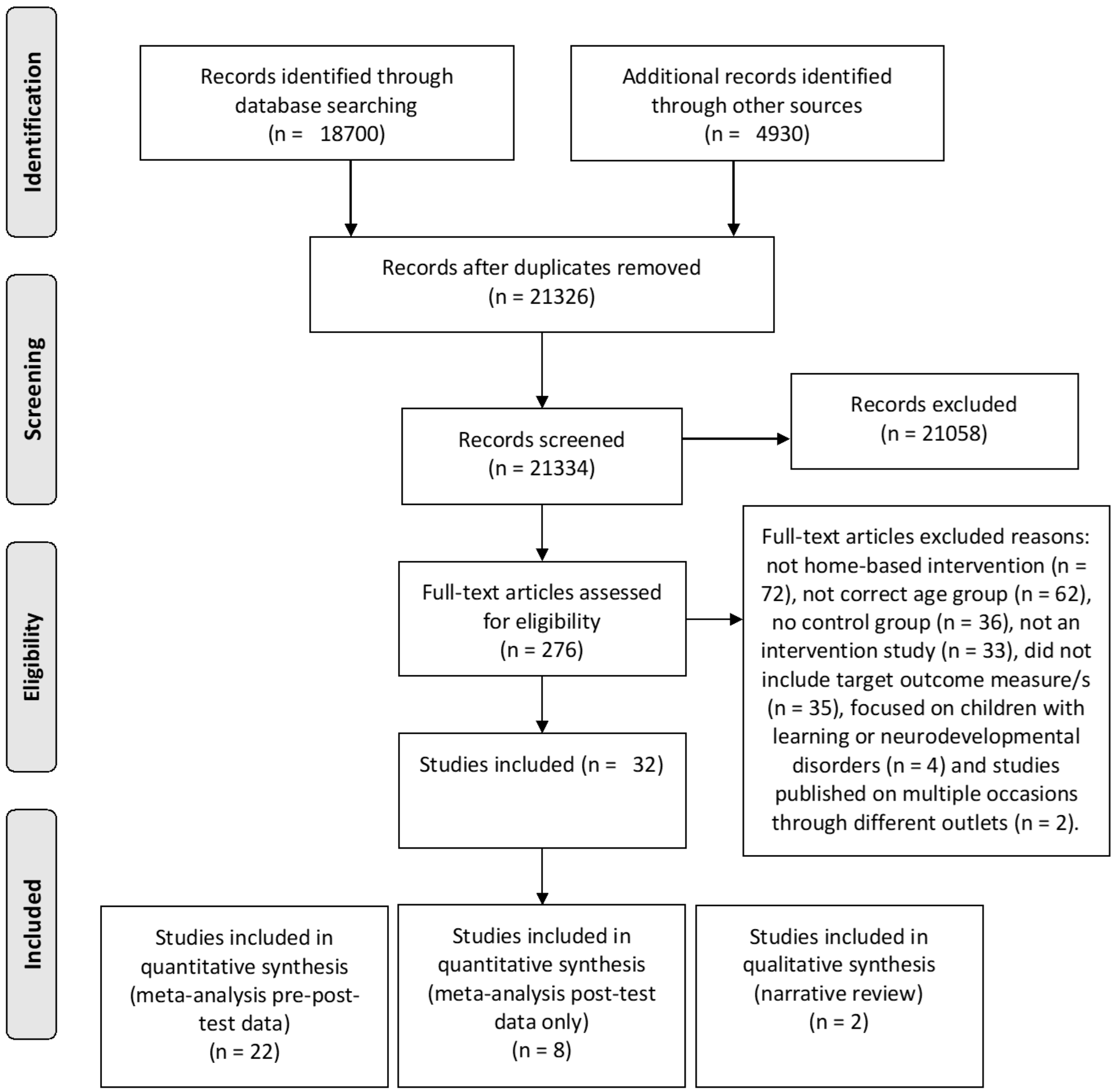
6. At least one follow-up at post-test was necessary for inclusion whether that was immediate post-test results (e.g., up to 30 days post intervention) or longer duration. If there are longer follow-up periods (e.g., after 6 months, after 12 months) then similar follow-up periods may be grouped.

Screening process

The PRISMA Flow Diagram summarising the screening process is shown in Figure 1. The literature database search yielded 18,700 articles and 4930 records through grey literature searching, the results were saved in RefWorks. Grey literature searching included examination of all included papers reference lists. An expert researcher was contacted to review the final included papers as well as suggest any papers they knew that might be relevant to our objective. This experienced researcher suggested six additional papers that they were aware of (only three of these papers met our inclusion criteria).

Figure 1

PRISMA Flow Diagram Article Selection



During the first review of articles, 2296 of the articles were rejected as duplicates. 20,427 were excluded based on title screening. Approximately 80% of the articles were title screened by the first author and 20% were screened by the last author. After title screening 10% of first author's articles were screened by the last author and vice versa. An inter-rater reliability of 99% was obtained at this stage. Two articles had no abstract so bypassed abstract screening and were included at full text review. 631 articles were excluded based on reviewing abstracts. We could not gain full text access to fifteen articles, four of these articles were excluded at the abstract screening stage. Again, 80% of the articles were abstract screened by the first author and 20% were screened by the last author. After abstract screening 10% of first author's articles were screened by the last author and vice versa, ending with inter-rater reliability of 99%.

Two-hundred-and-seventy-six articles were full-text screened. At this stage, we did not have access to the full text for eleven studies. Therefore, the first and/or corresponding author of these papers were contacted a total of three times over a period of 6-8 weeks. If they did not respond, or they were unable to give access to the article, the article was excluded. Three articles were excluded at this stage as the authors of these papers did not respond. We gained access to the full texts of eight articles by contacting the first or corresponding author. One paper that made it through to full text review was a conference abstract (Klein et al., 2011) and although the study was relevant, the conference abstract did not provide enough information to be included in the review. After contacting the authors of the conference abstract, they provided a published paper. Subsequent reasons for exclusion at the full-text screening stage were as follows; not home-based intervention (n = 72), not correct age group (n = 62), no control group (n = 36), not an intervention study (n = 33), did not include target outcome measure(s) (n= 35), focused on children with learning or neurodevelopmental disorders (n = 4) and studies published on multiple occasions through different outlets (n = 2)[2].

The outcome of the screening process resulted in 32 articles meeting inclusion criteria. Thirty studies included sufficient data for quantitative synthesis or inclusion in meta-analyses. Two studies did not contain sufficient quantitative data and instead were summarised in a narrative review. A reference list of all included studies is contained in the Supplementary Materials A.

Coding procedure

For the present meta-analysis, the studies that met the inclusion criteria were coded and data was extracted from each article (e.g., outcome measures, sample size, country of data collection) and recorded. The information that was extracted was coded under the following characteristics: study information (e.g., year of publication, country of data collection), methods (e.g., data points, total sample size), participants (e.g., age, gender), interventions (e.g., type of intervention), outcome measures (e.g., standardised tests used) and risk of bias (e.g., blinding of participants; see Supplementary Materials B for table showing coding procedure for studies included in this meta-analysis).

[2] Four studies (i.e., Bierman, Welsh, Heinrichs, Nix & Mathis, 2015; Bierman, Welsh, Heinrichs & Nix, 2018; Loughlin-Presnal & Bierman, 2017; Mathis & Bierman, 2015) reported data from one data set. It was apparent that three studies all reported data collected at the same time points. Therefore, one study was selected to be included in the current systematic review based on the reporting of relevant outcomes (i.e., Loughlin-Presnal & Bierman, 2017), specifically a composite score of emergent literacy. Therefore, Bierman et al. (2015) and Mathis et al. (2015) were excluded as they both reported on the same data included in Loughlin-Presnal and Bierman (2017). Bierman et al., (2018) was also included as it reported novel follow-up data (at 3rd grade).

Coding Interrater Agreement

Full texts of the final set of eligible studies were allocated and screened again by two members of the review team (e.g., second and third authors) and their inclusion was confirmed. The 30 articles that were to be used in the meta-analyses were divided for main data extraction among the three teams in Mexico, Cuba and the UK, each team involved two data extractors. The data/information that was extracted was then checked by the first author, who undertook the coding of all identified studies. Disagreements between the review team (e.g., the first and last author) were resolved by a different review team member (e.g., the second author) and consensus was achieved.

Data analysis plan

Effect sizes are calculated to evaluate the impact of interventions, this allows for a common scale to synthesise and compare studies effects in terms of magnitude and direction (Borenstein et al., 2009). The effect sizes were calculated using an online calculator (Lenhard & Lenhard, 2016). Most studies included in this meta-analysis reported statistics that allowed the calculation of effect sizes (i.e., Cohen's d). However, if the authors needed further information (e.g., the mean and standard deviation of the intervention and control groups separately) the corresponding author and/or the first author of that study were contacted. Two papers (i.e., Bierman et al., 2017; Nievar et al., 2018) had to be excluded from the meta-analyses as there was not enough information to calculate the effect size of the intervention. The authors had been contacted three times with no response/follow up. A narrative summary of these two studies has been provided at the end of the results section.

Six risks of bias criteria (i.e., random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessors, incomplete outcome data and selective outcome reporting) were used to quantify potential risk of bias in study methodology or reporting (see Appendix A, Table 1 for breakdown of risk of bias; see Table 1 for summary of overall risk of bias per study). Two authors (i.e., the first and last authors) completed the risk of bias on the 30 studies, with an interrater reliability of 95.6%.

The data used in the meta-analyses (i.e., both literacy and mathematics interventions), and the R script used to run both meta-analyses (for studies that had mathematical or literacy outcomes) and publication bias are available on the first authors OSF profile (i.e., DOI: 10.17605/OSF.IO/NM74Z). The coding procedure for the studies is available in Supplementary materials B.

Results

Descriptive results

A summary of the studies and intervention details is reported in Table 1. For a comprehensive list of literacy and mathematical outcomes (and their details) used within the included studies see Supplementary material C, Tables 1 (literacy outcomes) and 2 (mathematical outcomes).

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Table 1

Study and Intervention Information

First author (year)	Country	N (control/ intervention)	Child age (years)	Type of intervention	Nature of control	Selected literacy outcome	Selected maths outcome	Data points	Duration of intervention	Type of training	Resources and materials	Risk of bias
Anthony et al. (2014)	USA	617 (NA/NA)	4.5	Literacy	Business-as-usual control group	CTOPP	NA	Pre- and post-test	Family night 1.5hrs for 5 sessions	Parent training with child involvement outside of home	Storybooks	Low
Baroody et al. (2018)	USA	258 (128/130)	4.03	Maths intervention with literacy outcomes	Randomised control	TOPEL	NA	Post-test only	6 months (texts 3 times a week)	Low involvement intervention	Technology: Text messages	Uncertain
Bierman et al. (2018)	USA	200 (105/95)	4.45	Literacy	Comparison group	TOWRE	NA	Post-test only	10 home visits and 6 booster visits	Parent training with child involvement at home	Educational toys and storybooks (REDI-P)	Low

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Bierman et al. (2017) *	USA	200 (105/95)	4.48 (including two RCT)	Literacy	NA	NA	NA	NA	10 home visits and 6 booster visits	Parent training with child involvement at home	Educational toys and storybooks (REDI-P)	NA
Brotman et al. (2013)	USA	1050 (589/561)	4.15	Literacy	Randomised control (comparison group)	TOPEL	NA	Post-test only	13 weeks (2 hours per week)	Parent training outside of home	Information and strategies	Low
Cabell et al. (2019)	USA	174 (87/87)	4.5	Literacy	Randomised control (comparison group)	PALS-PreK	NA	Pre- and post-test	25 weeks	Low involvement intervention	Technology: Text messages	Low
Chow et al. (2008)	Hong Kong	148 (NA/NA)	5.32	Literacy	Comparison group	HKT-SpLD	NA	Pre- and post-test	12 weeks	Parent training outside of home	Storybooks	Low
de Chambrier et al (2020)	Switzerland, Belgium, Luxemb	569 (163/75)	5.05	Maths	Business-as-usual control group	NA	Adaption of TEDI-MATH	Pre- and post-test	12 weeks	Low involvement intervention	Maths games	Uncertain

	ourg & France						and TEDI-3					
Doyle (2009)	Canada	85 (30/54)	4.12	Literacy	Randomised control (comparison group)	Concepts about Print	NA	Pre/post-test and delayed post-test**	8 weeks (90 minutes per week)	Parent training outside of home	Information and strategies	Uncertain
Dulay et al. (2018)	Philippines	673 (164/166 numeracy & 120 literacy)	4.26	Intervention involved both literacy and maths	Randomised control	PWPA	Numeral identification	Pre- and post-test	12 weeks	Parent training with child involvement outside of home	Information and strategies	Uncertain
Evangelou et al. (2007)	UK	147 (83/64)	3.3	Literacy	Comparison group	Concepts about Print	BAS	Post-test only	33 weeks per year for 2 years	Parent training with child involvement outside of home	PEEP curriculum	Low

Ford et al. (2003)	UK	128 (33/33)	3.33	Intervention involved both literacy and maths	Randomised control	Letter recognition	Number recognition	Pre/post-test and delayed post-test***	6 weeks	Parent training at home	Storybooks	High
Ford et al. (2009)	UK	60 (31/29)	3.07	Intervention involved both literacy and maths	Matched control	Letter recognition	Number recognition	Pre/post-test and delayed post-test****	40 weeks (one visit per week 90-120 minutes)	Parent training with child involvement at home	Educational toys and storybooks	Low
Jordan et al. (2000)	USA	248 (71/177)	N/A	Literacy	Comparison group	CAP: Concepts about print: Reading	NA	Pre- and post-test	5 months (1 session per month)	Parent training outside of home	Storybooks	Uncertain
Justice et al. (2000)	USA	28 (14/14)	4.5	Literacy	Comparison group (given same material with no instruction)	Concepts about Print	NA	Pre- and post-test	4 weeks (16 sessions)	Low involvement intervention	Storybooks and technology	Uncertain

Konerza (2012)	USA	75 (35/40)	N/A	Literacy intervention with also numeracy outcome	Quasi-experimental study with control group	AIMS Web: Letter identification	AIMS Web: Number identification	Pre- and post-test	16 weeks (90 min classes)	Parent training with child involvement outside of home	NA	High
Kraft et al (2001)	USA	45 (23/22)	N/A	Literacy	Control group	WRMT-R	NA	Post-test only	4 months	Parent training outside of home	Storybooks	Uncertain
Landry et al. (2017)	USA	434 (111/323)	4.37	Literacy	Business-as-usual control group	TOPEL	NA	Pre- and post-test	19 sessions 1-1.5hrs weekly	Parent training with child involvement at home	PALS curriculum and technology	Uncertain
Loughlin-Presnal et al. (2017)	USA	200 (95/105)	4.8	Literacy	Control group (given same material with no	WJ III ACH, DIBELS & TOWRE	NA	Post-test only	16 months	Parent training with child involvement at home	Educational toys and storybooks	Uncertain

					home visits)							
Mendez (2010)	USA	288 (115/173)	4	Literacy	Waiting list control	Letter knowledge	NA	Pre- and post-test	9 months	Parent training outside of home	NA	Uncertain
Neville et al. (2014)	USA	141 (38/66)	NA	Literacy	Active control	P-IGDI	NA	Pre- and post-test	8 weeks	Parent training outside of home	LIFT curriculum	Low
Nievar et al. (2018) *	USA	254 (127/127)	NA	Literacy	NA	NA	NA	NA	3 years	Parent training at home	HIPPY curriculum	NA
Niklas et al. (2016)	Australia	106 (76/37)	4.42	Maths	Comparison group	NA	Counting	Pre- and post-test	2 sessions (30 mins)	Parent training with child involvement outside of home	Maths games	Uncertain

Pears et al. (2014)	USA	39 (14/25)	4.83	Literacy	Business-as-usual control group	Concepts About Print	NA	Pre- and post-test	2 months (2 hours twice a week)	Parent training outside of home	Storybooks	Low
Reese et al. (2010)	USA	33 (11/10)	4.12	Literacy	No training control group	Concepts About Print	NA	Pre- and post-test	5 months	Parent training outside of home	Technology and Storybooks	Uncertain
Scheepers et al. (2020)	South Africa	82 (40/42)	4	Literacy	Randomised control	ELLA: Concepts about Print	NA	Pre- and post-test	16-20 weeks	Low involvement intervention	Technology: Text messages	Uncertain
Sheridan et al. (2011)	USA	217 (116/101)	3.59	Literacy	Comparison group	TROLL: Reading	NA	Pre- and post-test	Getting Ready strategies was a 60-minute home visit conducted, on average, 8.35 times over 2 years.	Parent training with child involvement at home	Information and strategies	Low

Starkey et al. (2000) Study 1	USA	28 (14/14)	4.8	Maths intervention with also literacy outcome	Comparison group	Print awareness and reading conventions tasks	Enumeration and numerical reasoning tasks	Pre- and post-test	4 months in length (8 biweekly classes)	Parent training with child involvement outside of home	Family mathematics curriculum	Uncertain
Starkey et al. (2000) Study 2	USA	31 (14/16)	4.9	Maths intervention with also literacy outcome	Comparison group	Print awareness and reading conventions tasks	Enumeration and numerical reasoning tasks	Pre- and post-test	4 months in length (8 biweekly classes)	Parent training with child involvement outside of home	Family mathematics curriculum	Uncertain
Terry (2011)	USA	33 (16/17)	4.13	Literacy	Active control	PWPA: Print concepts knowledge	NA	Pre- and post-test	6 weeks	Parent training at home	Storybooks	Low
Wing-Yin Chow et al. (2003)	Hong Kong	86 (28/29)	5.31	Literacy	Comparison group	PPCLS	NA	Pre- and post-test	8 weeks (reading 2 books twice	Parent training outside of home	Storybooks	Low

									in a week for 15 min)			
Zimmerman et al. (2008)	USA	750 (441/163)	4	Literacy intervention with also numeracy outcome	Comparison group	SAT10	SAT10	Post-test only	Monthly meetings for 6 years	Parent training outside of home	Storybooks	Uncertain

Note: CTOPP = Comprehensive Test of Phonological and Print Processing; PALS-PreK = Phonological Awareness Literacy Screening for Preschool; PWPA = Preschool Word and Print Awareness; CAP = Comprehensive Assessment Program; TOPEL = The Test of Preschool Early Literacy; P-IGDI = Preschool Individual Growth and Development Indicators; ELLA = The Emergent Literacy and Language Assessment; TROLL = Teacher Rating of Oral Language and Literacy; HKT-SpLD = Hong Kong Test of Specific Learning Difficulties; PPCLS = The Preschool and Primary Chinese Literacy Scale; TOPEL = The Test of Preschool Early Literacy; SAT10 = The Stanford Achievement Test, 10th edition; TOWRE = Test of Word Reading Efficiency; WRMT-R = Woodcock Reading Mastery; WJ III ACH = Woodcock-Johnson Tests of Achievement III – Revised; DIBELS = Dynamic Indicators of Basic Early Literacy Skills; TEDI-MATH = Test for Diagnostic Assessment of Mathematical Disabilities; BAS = British Ability Scale; PEEP = Peers Early Education Partnership; PALS = Play and Learning Strategies; LIFT = Linking the Interests of Families and Teachers; REDI-P = Research-based Developmentally Informed Parent program; HIPPY = Home Instruction for Parents of Preschool Youngsters; RCT = Randomised Control Trial; * = Narrative review. ** Short term post-test took place immediately after intervention and delayed post-test took place 5 months after completion of the program. *** Short term post-test took place immediately after intervention and delayed post-test took place 6 weeks following the intervention. **** Short term post-test took place at the end of nursery class and delayed post-test took place 4 months after the first post intervention assessment.

Study information

All eligible studies were published between 2000 to 2020, with 27% being published between 2015 and 2020. The majority of the studies were conducted in the USA (n = 20; 67%). Additionally, studies were conducted in the UK (n = 3; 10%), China (n = 2; 7%) and four separate studies were conducted in Canada, South Africa, Philippines and Australia. A final study was cross-cultural involving data collection in Switzerland, Belgium, Luxembourg and France. See Table 1 for further details.

Methodological and participant characteristics

Most studies included pre- and post-test measures (n = 20; 67%), with some studies either only including post-test measures or having different measures used at pre- and post-test (n = 7; 23%). In the case of different measures being used at pre- and post-test, only the post-test measure was used. Two studies involved pre/post-test and delayed post-test (i.e., Doyle, 2009; Ford et al., 2003) and one study involved a post- and delayed post-test (i.e., Ford et al., 2009). In these studies, the duration between post-tests and delayed post-tests were 5 months, 6 weeks and 4 months, respectively. Overall, one third of participants in studies included in the review were recruited through HeadStart programmes. See Table 1 for further details.

Research question one: Are there more robustly assessed literacy interventions than mathematical interventions?

The types of interventions conducted were; literacy-focused (n = 22; 73%), two of which also collected mathematics outcomes, mathematics-focused (n = 5; 17%), two of which also collected literacy outcomes and one which collected only literacy outcomes, and three interventions that involved both literacy and mathematics outcomes (n = 3; 10%).

In relation to potential for bias in these studies, 16 (53%) studies did not provide enough information to determine an overall risk of bias (i.e., the six risks of bias variables mentioned earlier e.g., random sequence generation, allocation concealment; see Table 1) to be provided. Only two studies (i.e., Ford et al, 2003; Konerza, 2012) were given an overall rating of high risk of bias. There were 12 (40%) studies classified as low risk of bias. Of these studies classified as having low risk of bias, eleven were literacy-only interventions and one intervention involved both literacy and mathematics outcomes. Therefore, there are not only more literacy interventions meeting our inclusion criteria for the systematic review compared to mathematics interventions, but also after closer scrutiny more literacy interventions are classified as having low risk of bias compared to mathematics interventions.

Research question two: What types of home-based literacy and mathematical interventions or programmes are most effective for improvements in early educational outcomes for children between the ages of 3 and 5?

The interventions varied in the way in which training was delivered. Specifically, most studies involved parent training outside of the home (n = 18, 60%) and at home (n = 7, 23.3%). There were 5 fully remote interventions (16.7%) which did not involve parent training per se, but rather included resources (e.g., storybooks) or reminders (e.g., text messages) being sent to parents on a weekly basis, but requiring little parental input. Of the interventions that included parent training, 48% of the studies also involved direct training with the target children (n = 12). The types of interventions included within the review are summarised in Table 2.

Table 2

Breakdown of the Types of Interventions

		N (%)
Type of intervention	Literacy intervention only	20 (66.7)
	Maths intervention only	2 (6.7)
	Intervention that targets both literacy and maths	3 (10)
	Literacy intervention with both literacy and maths outcomes	2 (6.7)
	Maths intervention with both maths and literacy outcomes	2 (6.7)
	Maths intervention with literacy outcomes	1 (3.3)
Type of training	Parent training outside of home	11 (36.7)
	Parent training with child involvement outside of home	7 (23.3)
	Parent training at home	2 (6.7)
	Parent training with child involvement at home	5 (16.7)
	Low involvement intervention	5 (16.7)
Duration of intervention	8 weeks or less	8 (26.7)
	Duration 9 weeks of greater	9 (30)
	Duration 16 weeks of greater	13 (43.3)

The average number of sessions per included study was 13.52, with studies with mathematics outcomes having substantially more sessions than those with literacy outcomes (20.43 vs 14.12) . Overall, the average intensity of the interventions was 2.23 sessions per week, with studies with literacy and mathematics outcomes being of similar intensity (2.27 vs 2.31 sessions per week respectively). The average time spent engaging with the training for all included studies was 78 minutes with longer time spent engaging in interventions with literacy outcomes (81.2 minutes) compared to mathematics outcomes (65.75 minutes).

Meta-analysis results

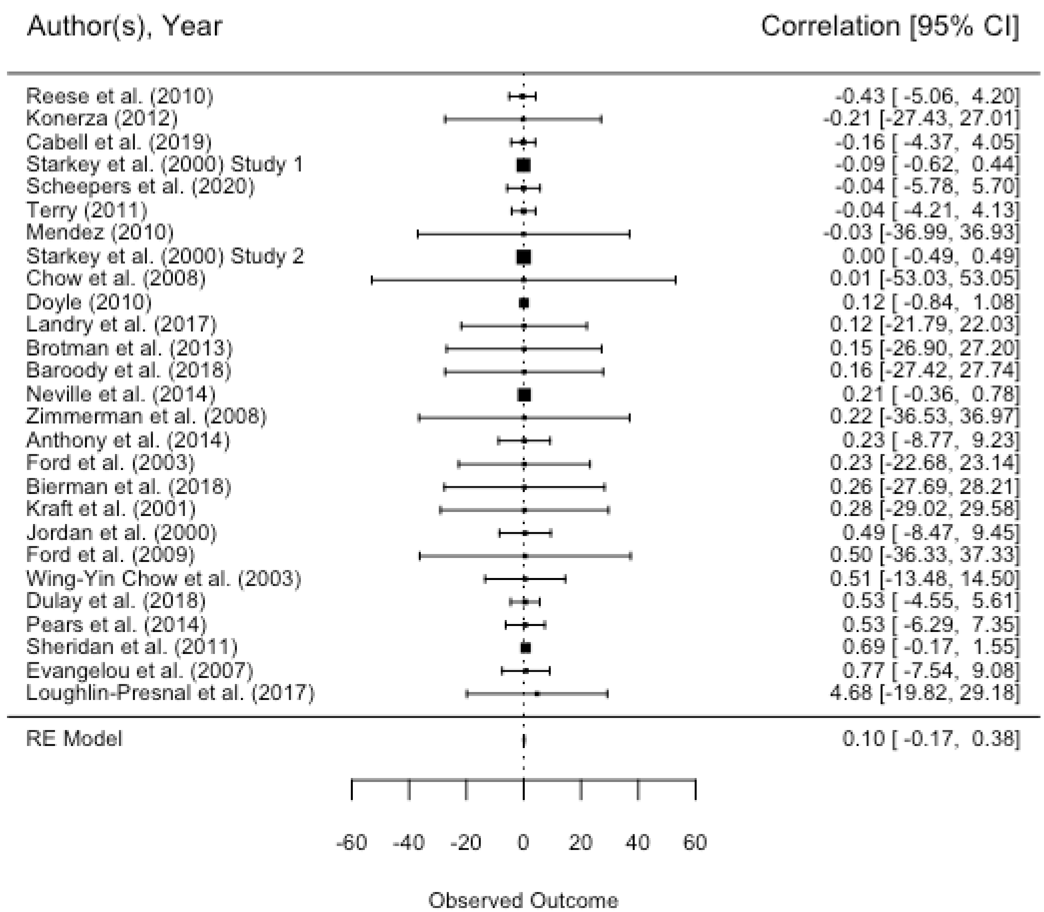
Weighted random mean effect size - interventions with literacy outcomes

The overall weighted random mean effect size was small-to-moderate, Cohen's d = 0.35 (SE = 0.21; range -0.06 to 0.75) for interventions with literacy outcomes (n = 28; Cohen, 1988). The test of heterogeneity was non-significant which suggests that the included studies share a common mean effect size ($Q(27) = 25.93$; $p = 0.52$) and 31.8% of the variability in effect sizes was due to heterogeneity rather than sampling error. A Baujat Plot (Baujat, Mahé, Pignon & Hill, 2002) was created and was used as a diagnostic plot to detect studies that substantially contributed to the heterogeneity of the meta-analysis. Studies that fall to the top right quadrant of the Baujat plot contribute most to both summary effect size and standard error (Appendix B, Figure 1). To understand which studies may exert a high influence over the meta-analysis results influence analyses was conducted (Appendix B, Figure 2), which established that five studies had a high influence over the results (specifically Justice et al. (2000), Neville et al. (2014), Sheridan et al. (2011) and Starkey et al. (2000) studies 1 and 2).

The Leave-One-Out-Method was used to understand the influence of these identified studies. In Leave-One-Out-Method analyses the study with the highest influence is left out and the results of the meta-analysis are recalculated. This allows for a better understanding of what influence individual studies may have in distorting the pooled effect size (Viechtbauer & Cheung, 2010). Justice et al. (2000) had a larger residual than other studies and was hence identified as an outlier and was selected as the study to be removed. After removal of this study, the overall weighted random mean effect size was small, Cohen's d = 0.10 (SE = 0.14; range -0.17 to 0.38; see Figure 2) for the 27 interventions with literacy outcomes. The test of heterogeneity was also non-significant which suggests that the final set of included studies share a common mean effect size ($Q(26) = 2.88$; $p = 1.00$) and 0.00% of the variability in effect sizes was due to heterogeneity rather than sampling error (see baujat plot Appendix B, Figure 3; influence analysis Appendix B, Figure 4).

Figure 2

Forest plot of interventions with literacy outcomes (n = 27)



Publication bias

There was evidence of publication bias when Justice et al. (2000) was included (n = 28) as the Rank correlation test (p = 0.04) was statistically significant. However, once Justice et al. (2000) was removed (n = 27) Egger's regression test (p = 0.80) was not statistically significant, indicating no evidence of publication bias. The Rank correlation test (p = 0.90) was also not statistically significant, corroborating that there was no evidence of publication bias across the included studies (see funnel plot Appendix B, Figure 5).

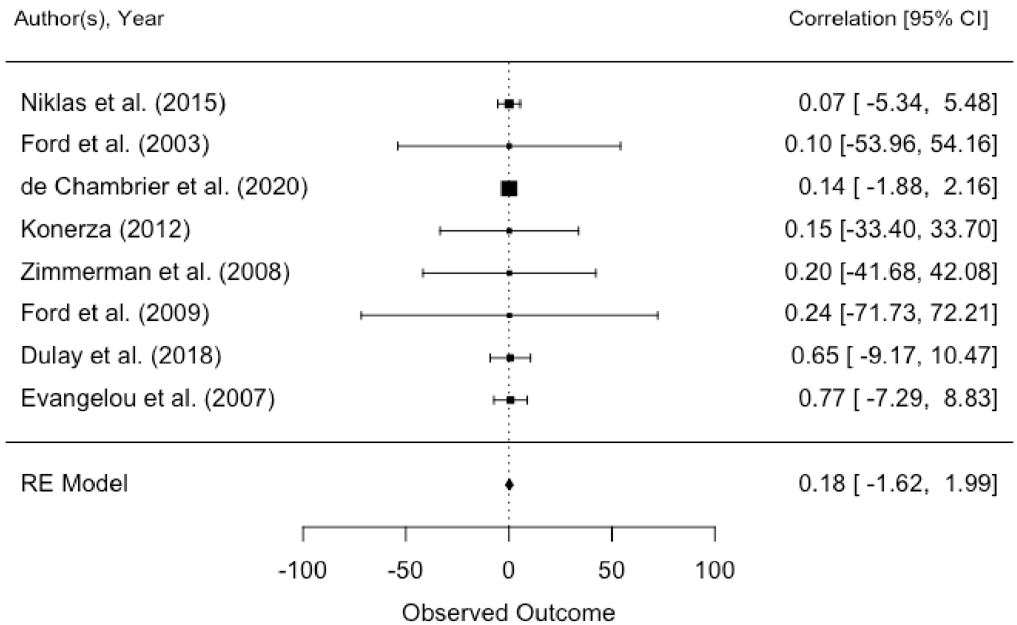
Weighted random mean effect size - interventions with mathematics outcomes

The overall weighted random mean effect size was moderate, Cohen's d = 0.65 (SE = 0.14; range 0.37 to 0.92) for interventions with mathematics outcomes (n = 10). The test of heterogeneity was non-significant which suggests that the included studies share a common mean effect size ($Q(9) = 0.37$; $p = 1.00$) and 0.00% of the variability in effect sizes was due to heterogeneity rather than sampling error.

A Baujat Plot was created, and an influence analysis was run (see Appendix C, Figure 1 through Figure 5 for Baujat Plots, influence analyses and funnel plot). Two studies had a high influence over the results (i.e., Starkey et al., 2000, studies 1 and 2). After removing the two identified studies, the overall weighted random mean effect size was small, Cohen's d = 0.18 (SE = 0.92; range -1.62 to 1.99; see Figure 3). The test of heterogeneity was non-significant which suggests that the final set of included studies share a common mean effect size ($Q(7) = 0.03$; $p = 1.00$) and 0.00% of the variability in effect sizes was due to heterogeneity rather than sampling error.

Figure 3

Forest plot of interventions with maths outcomes (n = 8)



Publication bias

Before the removal of the influential studies (i.e., Starkey et al., 2000, studies 1 and 2) Egger's regression test (p = 0.82) and Rank correlation test (p = 0.60) was not statistically significant. After the removal of the influential studies Egger's regression test (p = 0.94) and the Rank correlation test were not significant (p = 0.55), corroborating that there was no evidence of publication bias.

Summary of meta-analyses results

In summary, the overall weighted random mean effect size was 0.10 (SE = 0.14; range -0.17 to 0.38) for the interventions with literacy outcomes and the overall weighted random mean effect size was 0.18 (SE = 0.92; range -1.62 to 1.99) for the interventions with mathematics outcomes.

The overall effect sizes for both types of interventions were defined as small (Cohen, 1988). Therefore, the types of literacy and mathematics interventions that are most effective for improving early educational outcomes for children are unclear.

Research question three: What are the demographics of the participants that take part in these interventions, are there individual differences that impact the efficacy of these interventions?

Across all studies (n = 30), the average sample size was 232 participants (SD = 250.9; range 28 - 1050). The children ranged in age between 3.07 years to 5.32 years (overall mean age = 4.29; mean age of interventions with literacy outcomes = 4.26; mean age of interventions with maths outcomes = 4.23; 49.2% male).

The age of the child participants did not significantly moderate the observed impact of the interventions on literacy outcomes (p = 0.16). Gender (i.e., the total number of males and females in the control and intervention groups used for the effect size) also did not significantly moderate the observed relationship (p = 0.77). In addition, the age and gender of the children did not significantly moderate the observed impact of the interventions on mathematics outcomes (p = 0.8 and p = 0.98, respectively).

Research question four: Identify the resource requirements (i.e., materials) of these interventions.

The resources and materials used within these studies involved storybooks (n = 9), educational toys and storybooks (n = 3), maths games (n = 2), parent information and strategies (n = 4), technology used for text messages (n = 3) and technology used with curriculum or storybooks (n = 2). One intervention involved a program (i.e., Research-based Developmentally Informed Parent program (REDI-P)) and five interventions involved the following a curriculum: Peers Early Education Partnership (PEEP; n = 1), Play and Learning Strategies (PALS; n = 1), Linking the Interests of Families and Teachers (LIFT; n = 1) and Family mathematics curriculums (n = 2; see Table 1 for more detail). PEEP curriculum involves circle time (e.g., rhymes), talking time (e.g., parents share experiences), story time, book sharing, home activities (e.g., games and activities) and borrowing time (i.e., play packs). The PALS curriculum is guided by a manual and videotapes that aid parents to support their children during play and learning activities (e.g., shared book reading). The LIFT curriculum involves small group instructions, support calls, instruction points and suggestions on home-practice activities. Family mathematics curriculum aids parents' understanding on the level of support to provide to their children and a set of maths activities.

Narrative review

Two papers did not report sufficient information to be included in the meta-analyses (i.e., Bierman et al., 2017; Nievar et al., 2018), both studies included literacy and mathematics outcomes. Full details of these interventions are summarised in Table 1.

Bierman et al. (2017) investigated the influence of a home-visiting program (REDI-Parent program, REDI-P) over and above an existing Research based Developmentally Informed Classroom program (REDI-C) intervention on children's outcomes three years later (i.e., the end of second grade). The REDI-P program offered parents activities that taught letters and letter-sound recognition. Parents received 12 of the 16 planned home visits on average (SD = 5·48, range = 0 – 16). For the REDI-Parent program (REDI-P) 200 families were assessed and received either learning materials via home visits (REDI-P intervention; N = 105) or an alternative set of materials via mail (control group; N = 95). The three academic outcomes were emergent literacy skills, sight words and phonemic decoding scales, which were direct assessments with children. In addition, teachers rated academic performance (reading and maths skills). The REDI-P plus REDI-C group showed significantly higher second grade scores on three of the five academic outcomes (i.e., sight words, teacher-rated reading, and maths skills) compared to those who received REDI-C alone.

In addition, Nievar et al. (2018) focused on the impact of the Home Instruction for Parents of Preschool Youngsters (HIPPY) program; a 3-year home-based, early intervention program. Children who participated in the HIPPY home visits program (n = 127) were compared to children who participated in prekindergarten but did not receive home visits (254 families in both groups). Due to the nature of the study the exact age of the children during the intervention is unknown, however HIPPY participation occurs at enrolling before entering kindergarten, hence the children would be approximately 3-5 years old; the age group for inclusion in the current review. As this study was not a randomised trial results from the study are limited. Results indicated that children in the prekindergarten-only comparison group had lower reading and mathematics achievement scores at third, fourth and fifth grade than those children who received HIPPY and prekindergarten. Growth curve modelling indicated that the group that experienced home visiting displayed higher academic achievement than those who did not through to fifth grade.

Overall, these two home-visiting based interventions indicate long-term benefits for children's literacy and mathematics outcomes. However, due to the insufficient reporting of outcome data the extent of the benefits cannot be quantified.

Discussion

Overall, the results of the current systematic review and meta-analyses show that home-based interventions aiming to improve literacy and mathematics outcomes for preschool aged children had a minimal effect on literacy and mathematical outcomes. The residual heterogeneity showed no variability in the association between the interventions and children's literacy and mathematics outcomes indicating that all intervention impacted on children's outcomes to similar effect. However, a wide range of types of strategies and methodologies were found to be used in interventions, from training inside or outside the home to using technology or other resources. However, the meta-analyses indicated that these interventions had no differential impact on outcomes. Due to the preregistration of these meta-analyses, the moderators (i.e., age and gender) were investigated even though there was a lack of variability between studies. As expected, the age and gender of the children did not significantly moderate the observed impact of the interventions with literacy or mathematics outcomes.

This systematic review established that there are substantially more home-based interventions focused on improving literacy (N = 28) rather than mathematical outcomes (N = 10). This is consistent with most narrative reviews of the literature indicating that research has predominantly focused on the HLE (i.e., parents helping their children to read words and the frequency of shared reading; Skwarchuk et al., 2014) in comparison to the HME (i.e., parents helping their children to count; Kirby & Hogan, 2008; LeFevre et al., 2009; Sénéchal & LeFevre, 2002). Children's activities in formal educational environments are dominated by literacy-based activities, for example, Paro et al. (2009) observed that 28% of pre-schoolers' time was spent on language and literacy instructions. Meanwhile, less than 10% of instructional time was spent on other areas of the curriculum (e.g., mathematics). The current review indicates that this imbalance of focus is also reflected in the development and assessment of interventions focusing on informal contexts (i.e., the home). Given that evidence suggests that school entry mathematical skills are more important predictors of later mathematical, reading and science achievement than school-entry reading skills (Claessens & Engel, 2013) the current findings emphasise the need for an increased focus on the development and assessment of efficacy of home-based interventions for pre-schoolers mathematics skills.

In the context of the growing body of literature on the importance of the home learning environment and parent-child interactions for early learning (Hornburg et al., 2021; Nelson et al., under review), the overall findings of the meta-analyses may appear surprising. Previous correlational and longitudinal studies have emphasised the relationship between resource-rich home environments and supportive parental scaffolding for early and later academic achievement (Lehrl et al., 2021a). Our meta-analyses have established a minimal, but consistent, positive effect of parent-focused interventions on both early mathematics and literacy skills. A recent meta-analysis of large-scale efficacy and effectiveness randomised control trials in education (including children from preschool through to the end of secondary school) indicated negligible gains in attainment (SD = .06, Lortie-Forgues & Inglis, 2019). Thus, in this context the minimal, but stable, overall effect size for home-based interventions may be encouraging. The heterogeneous impact of the interventions included in the current review was striking, suggesting that the specific interventions included in the studies, although broad in their approaches, had similar effects. These data add to the building correlational literature on the relationship between the home environment and educational outcomes, indicating that this relationship is, in fact, causal. However, we must recognise that these meta-analyses suggest that the impact of home-based interventions are not as substantial as previously thought. Nevertheless, there are several potential explanations as to why the impact of these interventions may have been so low.

Overall, the interventions included in this synthesis were relatively light touch in their approach, exemplified by a low average time spent engaging in parent training (i.e., 78 minutes). Further, the engagement requirement of the parent in some studies was minimal (e.g., reading a short text message). Therefore, the expectation for parents to implement and transfer relevant information from training (generally delivered outside of the home) to their interactions with their child at home may have been overly ambitious. A recent broader meta-analysis, involving home and school based mathematical interventions for 3-8-year-olds has indicated that the level of parental training is the only significant moderator of the impact of interventions on child outcomes (Nelson et al., under review). Therefore, the low intensity of the interventions of studies included in the current review may explain the overall observed minimal effect. Several interventions provided parents with resources with minimal support or instruction, this too may have led to issues with implementation of desired interactions between parents and their children.

In addition, the content focus of the interventions may have also led to the observed minimal effect on outcomes. The outcome measures were diverse and required different skill sets to be developed to ensure success. The development of literacy and numeracy skills are reliant on bolstering foundational skills (e.g., phonetic awareness and basic quantity processing, respectively). However, especially in relation to early numeracy development, there is a lack of clarity on the specific skills that are important for future development and the order in which they should be learnt (e.g., Cahoon et al., 2021). Thus, it is not perhaps unsurprising that interventions that are based on somewhat unclear theoretical grounds may be minimally successful. Literacy skill development is much better understood, with a more developed evidence base indicating that shared-book reading is an important activity for children's literacy development (Sim & Berthelson, 2014). The current review notes a dominance of literacy interventions using storybooks as an intervention resource. However, it is important to note that the overall effect on literacy skills was also minimal. Some interventions focused on literacy skills but measured both literacy and numeracy outcomes. In this context, the weak impact on numeracy skills, especially in this age group, may be expected given that mathematical specific interventions have been previously observed to be most effective for improving early numeracy outcomes (Raghubar & Barnes, 2017). Some interventions (e.g., Ford et al., 2003) were very broad, including a wide range of training activities rather than focusing on specific skills. Therefore, these types of interventions may have required great intensity to gain improvements in quite targeted outcome measures.

Finally, it is important to note that many of the included studies in the review did not include assessment of the fidelity of the intervention application (N=20, 62.5%). Also, many studies did not assess if there were any changes in parent behaviour (N=19, 59.4%) in response to the intervention. Therefore, in this context the potential reasons that only minimal impact of interventions were observed are two-fold: (1) that well-developed interventions training procedures were not applied in a consistent and rigorous way, and/or (2) that training elements of interventions did not lead to changes in parental behaviour. Previous literature has indicated the importance of considering the differential ways in which parents implement activities that they have been trained to engage in when independently interacting with their children at home (see Linder et al., 2013). As data on these aspects of the interventions were not captured in many cases, the reasons for minimal impact remain unclear. Importantly, 53% of included studies did not contain sufficient information to inform a decision on risk-of-bias. Therefore, there is potential that implementation of these interventions may have affected their impact. However, this cannot be ascertained from the published materials. It should also be noted that three articles were excluded at the full text screening stage as the authors of these three articles did not respond to our request. Although, this was out of our control we acknowledge that these three articles could have met our screening criteria but that we could not make that judgement.

Despite these potential explanations (as to why the impact of the interventions were minimal) it is important to note that perhaps home-based interventions may simply not be effective. However, the assessment of well-designed home-based interventions (i.e., that complete theory of change models, logic models, feasibility studies, pilot evaluations, quality assurance systems etc.) are necessary to understand if home-based interventions are effective (Early Intervention Foundation; Asmussen, Brims & McBride, 2019).

Implications for future research

Overall, the current review identified considerably more home-based interventions focused on improving literacy rather than numeracy skills. Given the known importance of preschool numeracy skills for future achievement and economic success (Hoff, 2003; World Bank, 2015) attention should be given to theoretically grounded, rigorously assessed numeracy interventions for this age group. This should be a priority for educational and psychological researchers both in terms of understanding the causal influence of the home environment on children's numeracy development and to provide practical evidence-based advice for parents to improve children's outcomes.

Due to the homogenous impact of the interventions included in this review on child outcomes, future research should examine not only the type of intervention, but also look more closely at the specific skills that are being delivered through training (e.g., verbal counting, letter recognition) or whether the information provided was more conceptual or procedural in nature (Mathe et al., 2011). This may provide further insight into the specific components that are important to support children's learning. In addition, future interventions should be manipulated in length and intensity to understand the necessary level of input to affect change in parent behaviour. This requires researchers to measure the fidelity of the delivery of any training and measurement of parent behaviour. However, no studies used measures of treatment fidelity to evaluate the change in parenting behaviour therefore we cannot comment on whether parents actually engaged with the interventions as intended.

Many studies included in the current review provided training outside of the home with the expectation that parents would transfer these skills to the home environment. Few interventions provided ongoing support to parents (e.g., check-in phone calls) to address queries or difficulties that parents may have during the intervention process. Thus, training for transfer of skills- such as worked examples of how to use specific activities within individual home contexts- and top-up support may lead to more favourable outcomes. This should be explored systematically in future research.

The inconsistences of the duration of follow-up across studies (i.e., Doyle, 2009; Ford et al., 2003, 2009; see Table 1 notes) meant that the long-term effectiveness and efficacy of the interventions could not be explored. Thus, there is no way to conclude the long-term effectiveness and efficacy of home-based interventions due to lack of follow-up data, a significant missed opportunity. Long-term follow-ups are essential to ascertain the longevity of impact of (often expensive) interventions, these data are essential to inform public policy and evidence-based investment. In addition, this finding highlights the difficulty in undertaking intervention studies, such as the problematic nature of long-term follow-up because of attrition and lack of long-term funding to collect follow-up data. Assessments of long-term effects of preschool interventions show a declining impact of interventions at follow-up, even for interventions that show success initially (Bailey, Duncan, Odgers & Yu, 2017; Durkin, Lipsey, Farran & Wiesen, 2022; Puma, Bell, Cook & Heid, 2010). Bailey et al. (2017) suggests that intervention evaluations should extend beyond the “fadeout window” of 12 months, so that foundational skill-based mechanisms that help provide children with the necessary skills at a key developmental timepoints can be rigorously tested in the long-term. Intervention-induced impacts of foundational skill-based mechanisms may fade out because children may have coincidentally acquired these types of skills without intervention. Therefore, to truly investigate the building blocks for the development of numerical skills, long-term follow-up studies are required (Cahoon, Gilmore & Simms, 2021). Our study highlights the need for investment in generating these types of data.

The review team experienced difficulties in accessing the necessary data to screen identified articles, perform meta-analyses and to assess risk-of-bias. Researchers should be encouraged to follow reporting standards for intervention research (Simms et al., 2019) to aid evidence synthesis and assess rigour of research. Similar standards have been commonly adopted in medical sciences, etc. In addition, preliminary research, such as the use of participatory research groups and feasibility studies, may also be necessary to develop interventions and increase their potential to generate positive benefits for child outcomes (Asmussen et al., 2019).

Conclusion

These meta-analyses demonstrate a minimal but consistent, positive effect of parent-focused interventions on both early mathematics and literacy skills, and this may be encouraging as this is larger than high-powered school-based interventions (SD = .06, Lortie-Forgues & Inglis, 2019) hence, perhaps interventions should target informal learning environments rather than school-based learning environments. Given that the findings of the current review revealed a minimal effect of home-base interventions on both literacy and mathematical outcomes, it is important to conduct more in-depth research into the components of theoretically driven interventions (e.g., focus of the intervention, parent training approaches) that may lead to the development of these skills. There is an imbalance in intervention types (i.e., literacy or mathematics) focusing on informal contexts, given that school entry mathematical skills are so important attention should be given to theoretically grounded, rigorously assessed mathematical interventions. Implementation of science principles should be applied to these types of studies to pinpoint the source of the weak effects identified in the current meta-analyses. This will enable practitioners and researchers to determine how best to provide and target effective interventions within the home.

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Appendix A: Risks of Bias

Table 1

Risks of Bias

Name of study	Random sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding of outcomes assessors	Incomplete outcome data	Selective outcome reporting
Anthony et al. (2014)	Low	Uncertain	Uncertain	Low	Low	Low
Baroody et al. (2018)	Low	Uncertain	Uncertain	Uncertain	Low	Low
Bierman et al. (2018)	Uncertain	Low	Uncertain	Low	Low	Low
Brotman et al. (2013)	High	Uncertain	Low	Low	Low	Low
Cabell et al. (2019)	Uncertain	Low	Uncertain	Low	Low	Low
Chow et al. (2008)	Uncertain	Uncertain	Uncertain	Low	Low	Low
de Chambrier et al (2020)	High	Uncertain	Uncertain	Uncertain	High	Low
Doyle (2009)	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Low
Dulay et al. (2018)	Low	Uncertain	Uncertain	Uncertain	High	Low
Evangelou et al. (2007)	High	Uncertain	Low	Uncertain	Low	Low
Ford et al. (2003)	Uncertain	High	Uncertain	High	High	Low
Ford et al. (2009)	Uncertain	Low	Uncertain	Low	High	Low
Jordan et al. (2000)	Uncertain	Uncertain	High	Uncertain	Uncertain	Uncertain
Justice et al. (2000)	High	Uncertain	Uncertain	Uncertain	Uncertain	Low
Konerza (2012)	High	Uncertain	High	Low	High	Low
Kraft et al (2001)	Uncertain	Uncertain	Uncertain	Uncertain	Low	Low
Landry et al. (2017)	Uncertain	Uncertain	Uncertain	Uncertain	High	Low
Loughlin-Presnal et al. (2017)	High	Uncertain	Uncertain	Uncertain	Low	Low

Mendez (2010)	Uncertain	Uncertain	Low	Uncertain	Uncertain	Low
Neville et al. (2014)	Uncertain	Low	Uncertain	Low	Low	Low
Niklas et al. (2015)	High	Uncertain	Uncertain	Uncertain	Low	High
Pears et al. (2014)	Uncertain	Low	Low	Uncertain	Low	Low
Reese et al. (2010)	Uncertain	Uncertain	Uncertain	Uncertain	High	Low
Scheepers et al. (2020)	High	Uncertain	Uncertain	Uncertain	Low	Low
Sheridan et al. (2011)	Uncertain	Low	Uncertain	Uncertain	High	Low
Starkey et al. (2000) Study 1	Uncertain	Uncertain	Uncertain	Low	Uncertain	Low
Starkey et al. (2000) Study 2	Uncertain	Uncertain	Uncertain	Low	Uncertain	Low
Terry (2011)	High	Uncertain	Low	Uncertain	High	Low
Wing-Yin Chow et al. (2003)	Uncertain	Uncertain	Uncertain	Low	Low	Low
Zimmerman et al. (2008)	Uncertain	Uncertain	Uncertain	Uncertain	High	Low

Appendix B: Interventions with literacy outcomes

Figure 1

Baujat plot for interventions with literacy outcomes (n = 28)

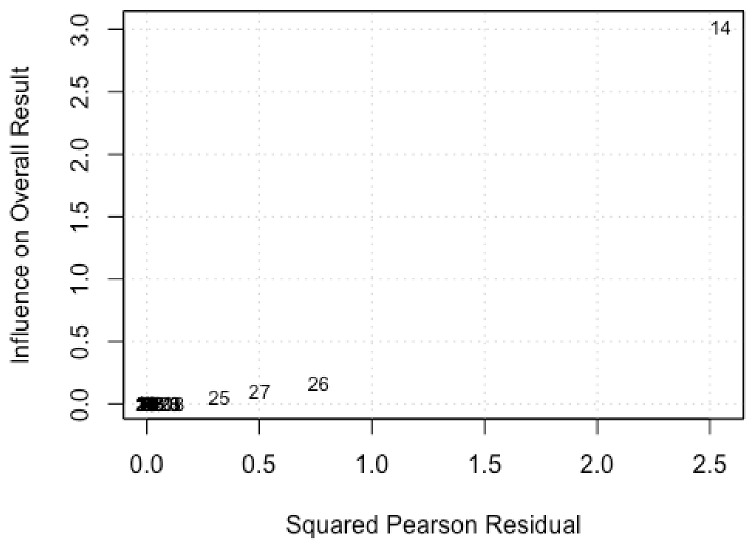
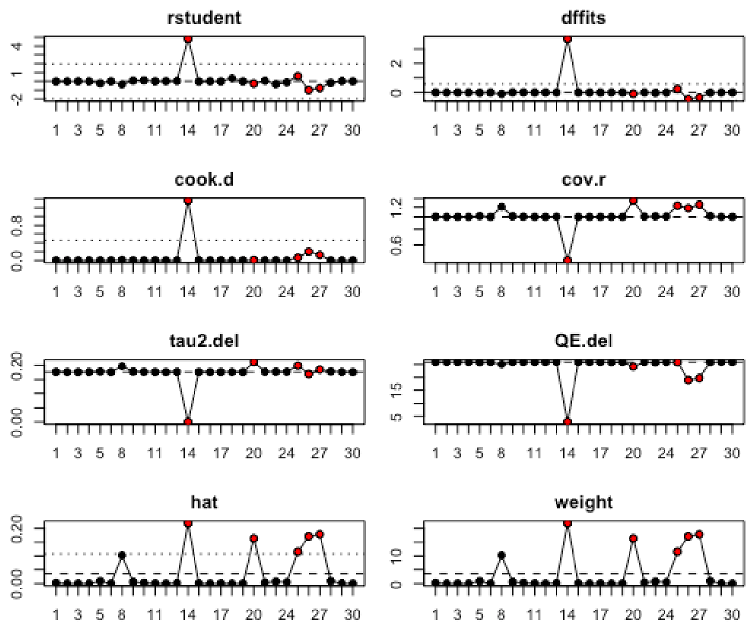


Figure 2

A Variety of Outlier and Influential Case Diagnostics (n = 28)



The figure shows a plot of the (1) externally standardized residuals, (2) DFFITS values, (3) Cook's distances, (4) covariance ratios, (5) leave-one-out estimates of the amount of heterogeneity, (6) leave-one-out values of the test statistics for heterogeneity, (7) hat values, and (8) weights.

Figure 3

Baujat Plot for Interventions with Literacy Outcomes with Justice et al. (2000) removed (n = 27)

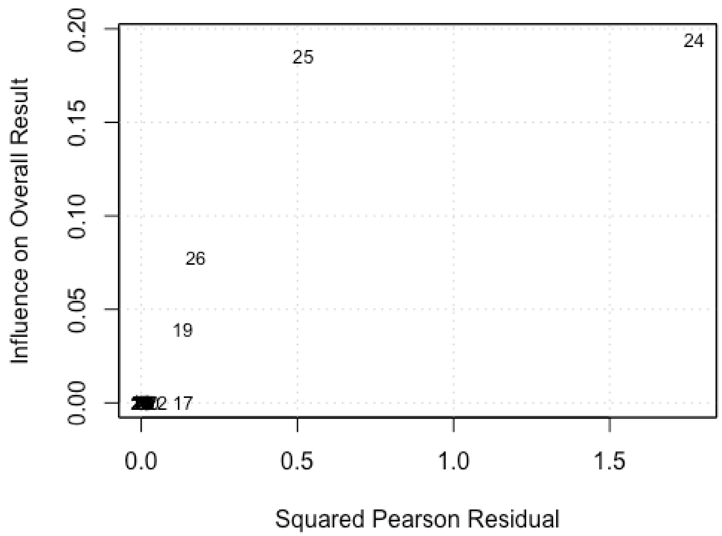
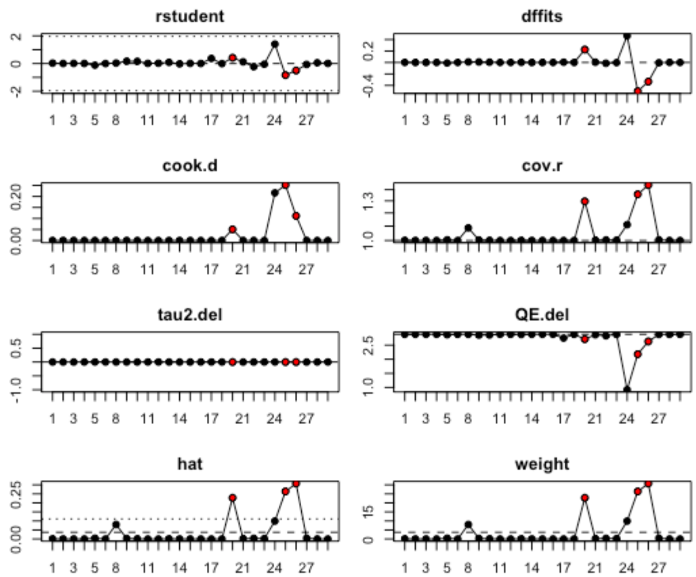


Figure 4

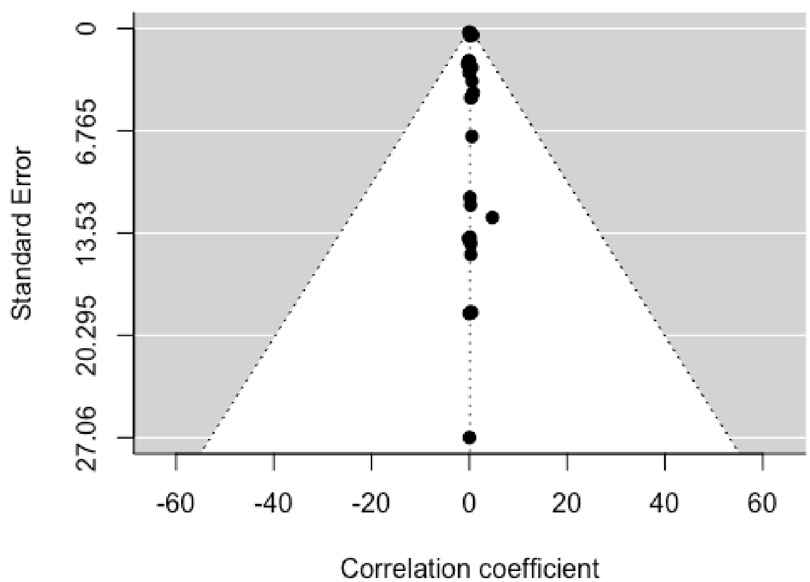
A Variety of Outlier and Influential Case Diagnostics (n = 27)



The figure shows a plot of the (1) externally standardized residuals, (2) DFFITS values, (3) Cook's distances, (4) covariance ratios, (5) leave-one-out estimates of the amount of heterogeneity, (6) leave-one-out values of the test statistics for heterogeneity, (7) hat values, and (8) weights.

Figure 5

Funnel Plot used to Investigate Publication Bias in Meta-analysis (n = 27)



Appendix C: Interventions with mathematical outcomes

Figure 1

Baujat plot for interventions with maths outcomes (n = 10)

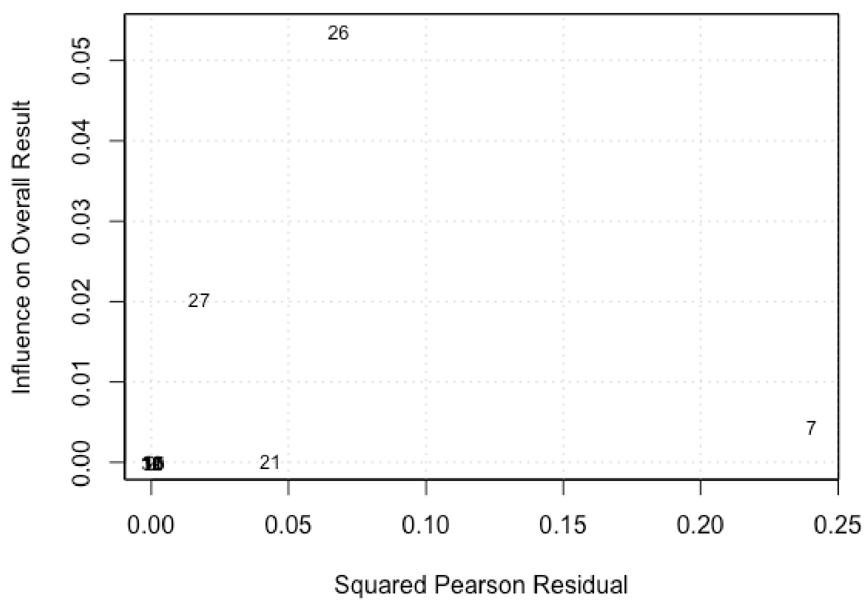
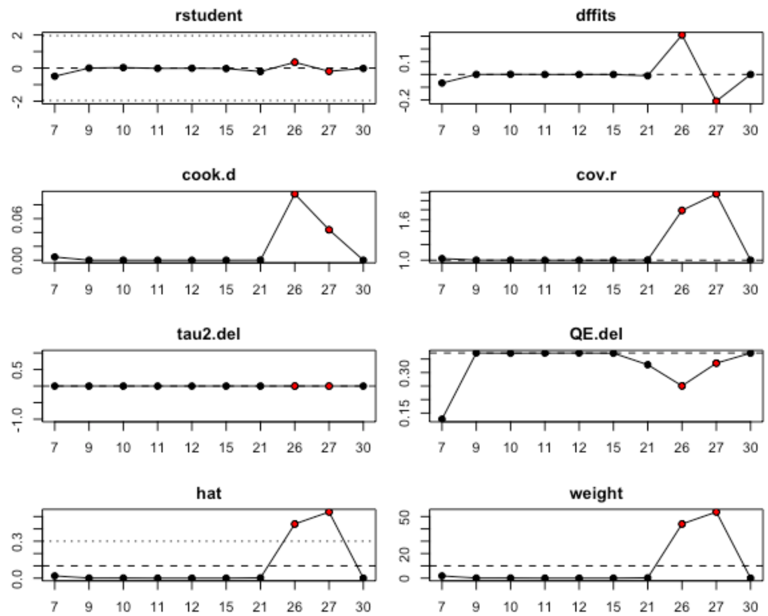


Figure 2

A Variety of Outlier and Influential Case Diagnostics (n = 28)



The figure shows a plot of the (1) externally standardized residuals, (2) DFFITS values, (3) Cook's distances, (4) covariance ratios, (5) leave-one-out estimates of the amount of heterogeneity, (6) leave-one-out values of the test statistics for heterogeneity, (7) hat values, and (8) weights.

Figure 3

Baujat Plot for Interventions with Maths Outcomes with both Starkey Studies Removed (n = 8)

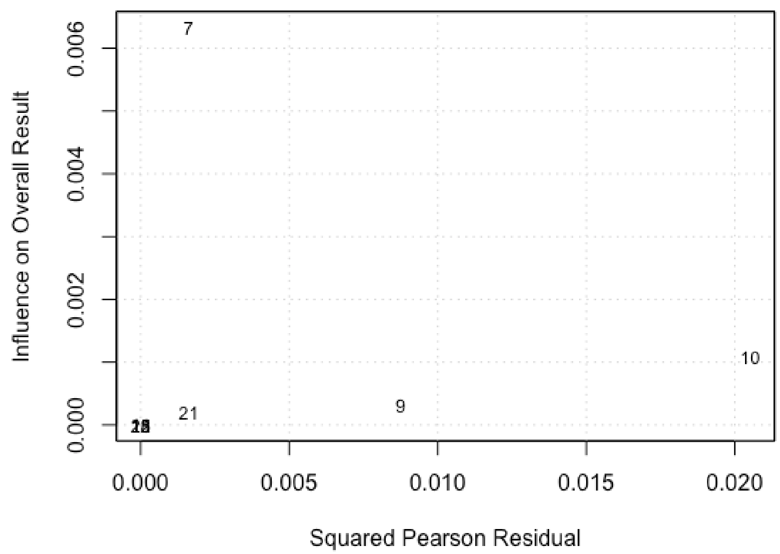
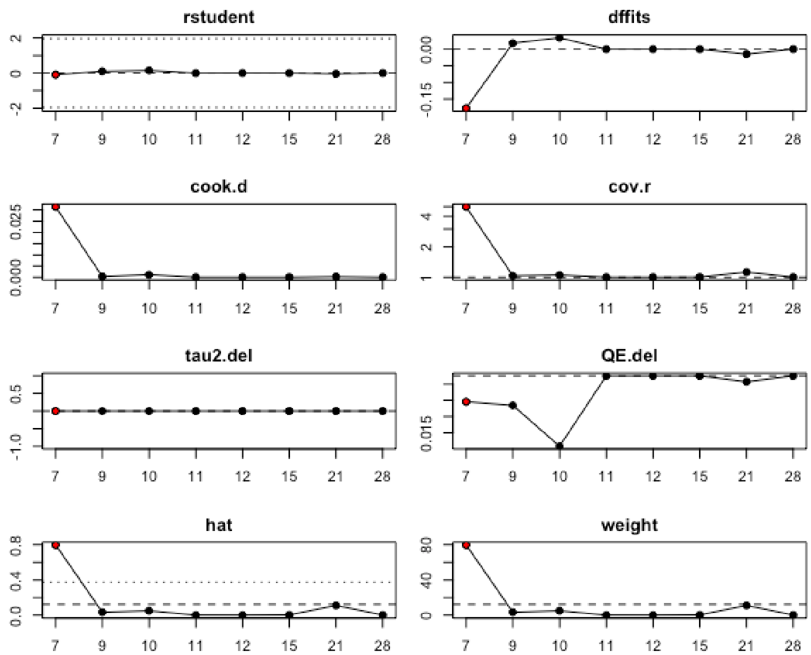


Figure 4

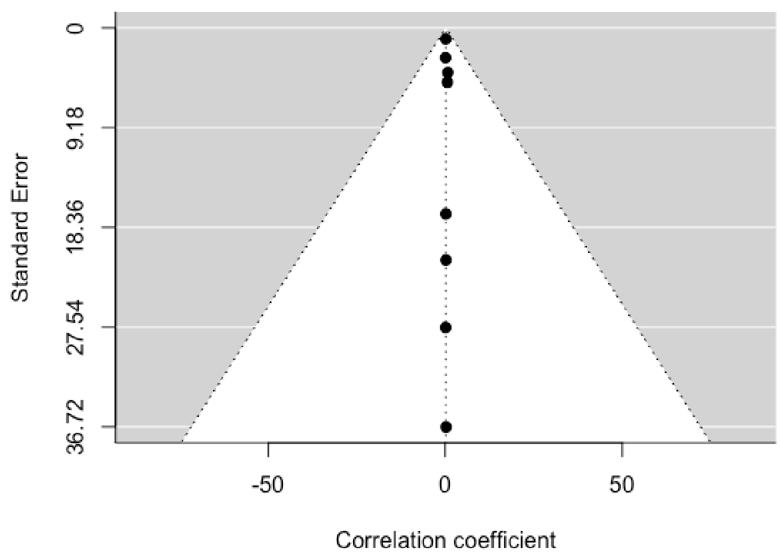
A Variety of Outlier and Influential Case Diagnostics (n = 27)



The figure shows a plot of the (1) externally standardized residuals, (2) DFFITS values, (3) Cook's distances, (4) covariance ratios, (5) leave-one-out estimates of the amount of heterogeneity, (6) leave-one-out values of the test statistics for heterogeneity, (7) hat values, and (8) weights.

Figure 5

Funnel plot used to investigate publication bias in meta-analysis (n = 8)



Meta-analyses and narrative review of home-based interventions to improve literacy and mathematics outcomes for children between the ages of 3 and 5 years old

Supplementary material A: Meta-analyses and narrative review references

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Supplementary material B: Coding procedure

Table 1

Coding Procedure for Studies Included in this Meta-Analysis

I. Study Information

Variable	Code Options	Explanation
Year of publication	Number between 2000 - 2020	Year of publication
Country	Country name coded first; for analyses, converted to: 0 = United States 1 = Canada 2 = South Africa 3 = China 4 = Philippines 5 = UK 6 = Cross-cultural 7 = Australia	Country where study was conducted

II. Methodological Characteristics

Variable	Code Options	Explanation

Data points	Selected one: 0 = Pre- and post-test 1 = Post-test only 2 = Pre/post-test and delayed post-test	Codes defined as: · Pre- and post-test = Researchers gave both a pre- and post-test to measure the effect of the intervention using the same measures at both time points · Post-test only = Researchers gave only a post-test to measure the effect of the intervention or different pre- and post-test measures were given and hence only the post-test measure is used in the meta-analysis · Pre-/post-test and delayed post-tests = Researchers gave a pre-, post-, and delayed post-test to measure the effect of the intervention
Total sample size	Number	Total number of children, parents, parent-child dyads or families
Treatment sample size	Number	Total number of children, parents or families per treatment group
Control sample size	Number	Total number of children or families per control group

III. Participant Characteristics

Variable	Code Options	Explanation
Age	Mean age of participants	Coded as years; converted “months” to years and “years, months” to years
Gender	Number, percent of participants identified as: a) Female b) Male	Total number and percent of participants identified in each category.

IV. Intervention Characteristics

Variable	Code Options	Explanation
Type of intervention	0 = Literacy intervention only 1 = Maths intervention only 2 = Intervention that targets both literacy and maths 3 = Literacy intervention with both literacy and maths outcomes 4 = Maths intervention with both maths and literacy outcomes 5 = Maths intervention with literacy outcomes	Literacy intervention only targets only interventions related to
Type of training	Selected as many codes that apply: 0 = Parent training outside of home 1 = Parent training with child involvement outside of home 2 = Parent training at home 3 = Parent training with child involvement at home 4 = Low involvement intervention	Codes defined as: Parent training outside of home = parent training and/or instruction in activities, not in person contact including over the phone communication and training. Parent training with child involvement outside of home = parent training and/or instruction in shared activities and time for parents to practice the new techniques with their own children. Parent training at home = parent training at home involving instruction in activities. Parent training with child involvement at home = parent training at home and/or instruction in shared activities and time for parents to practice the new techniques with their own children. Low involvement intervention = Resources given: Parents are not overly involved, text message

		intervention, books or games sent home weekly with reminders
Duration	Days, weeks, or months; recoded as weeks. For the purpose of analyses, duration was re-coded as: 0 = duration is 8 weeks or less 1 = duration is greater than 8 weeks 2 = duration is greater than 16 weeks	The total duration of the intervention from the first session to the last session
Intensity	Number of sessions per day, week, month, year	Coded as the frequency of the intervention (e.g., 2 per week)
Number of sessions	Total number	Coded as the total number of sessions that the intervention lasted; for analyses, this variable was calculated if the total number of sessions was not provided (i.e., total number of weeks number of sessions per week).
Length of Training	Minutes	Coded as the average number of min each intervention session lasted; for analyses, if the session length was provided as a range (e.g., sessions lasted 15 to 20 min, the mean of the two numbers was used). The length of training was defined as the length of one-to-one training sessions with the research and parent

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Supplementary material C: Literacy Outcomes and Descriptions

Table 1

Literacy Outcomes and Descriptions

Assessment	Description What is measured?	Reliability (a)
Comprehensive Test of Phonological and Print Processing (CTOPP) [1]	Print knowledge assesses a child's ability to distinguish printed letters or words from non-alphabetic characters and illustrations.	.87 [2]
Phonological Awareness Literacy Screening for Preschool (PALS-PreK) [3]	Print knowledge is measured through print-concept knowledge (i.e., Print and Word Awareness task[4]) and alphabet knowledge (i.e., Upper-Case Alphabet Recognition task and Lower-Case Alphabet Recognition tasks).	.75 - .99 [4]
Concepts About Prints [5]	Print Concepts was administered during shared reading which features large print and multiple instances of embedded, contextualized print within the illustration.	.77 [6]
The Test of Preschool Early Literacy (TOPEL)	Print knowledge subtest assess letter recognition, book and print concepts.	.96-.97 [7]
Letter knowledge	Letter knowledge. Children were shown a series of letter plates and were directed to indicate which letters of the alphabet they could expressively identify.	NA
Comprehensive Assessment Program (CAP)	The CAP covers Language, Sound and Print. In the print composite there are six measures: uppercase letter recognition; lowercase letter recognition; concepts of print: books; concepts of print: reading; environmental print in context; and environmental print out of context.	NA

The Emergent Literacy and Language Assessment (ELLA)	ELLA assesses three main domains of emergent literacy; orientation to print skills, knowledge of speech-print relationships and language.	NA
Preschool Word and Print Awareness (PWPA) [8]	Print-concept knowledge measures word and print awareness modelled after the early literacy assessment Concepts about Print.	.74 [9]
Teacher Rating of Oral Language and Literacy (TROLL)	The TROLL is designed to evaluate development of language and literacy skills across three constructs (i.e., Language Use, Reading, and Writing) including teacher-report and direct child assessment components.	.77-.92 [10]
Preschool Individual Growth and Development Indicators (P-IGDI)[11]	P-IGDI uses three measures (i.e., initial sound matching, rhyming, and letter awareness) to measure early literacy and phonological awareness.	NA
Hong Kong Test of Specific Learning Difficulties in Reading and Writing (HKT-SpLD) [12]	Chinese character recognition.	.98 [12]
The Preschool and Primary Chinese Literacy Scale (PPCLS)[13]	Character Identification and Visual and Auditory Discrimination.	.84[13]
AIMS Web[14]	The AIMS Web can measure children's academic knowledge using three tests: letter identification, number identification, and oral counting.	NA

Print awareness and reading conventions tasks	Assesses emergent literacy	NA
The Stanford Achievement Test, 10th edition (SAT10)[15]	Reading and Mathematics.	.88 to .96[16]
Test of Word Reading Efficiency (TOWRE)[17]	Sight words.	.85 to .90[18]
Woodcock Reading Mastery (WRMT-R)	Assesses reading readiness and reading achievement.	NA
Dynamic Indicators of Basic Early Literacy Skills (DIBELS)[19]	Assess early reading skills.	NA
Woodcock-Johnson Tests of Achievement III – Revised (WJ III ACH)[20]	Letter-Word Identification scale measures reading decoding.	NA

Note. Citations: [1]Lonigan, Wagner, Torgesen, & Rashotte, 2002; [2]Anthony et al., 2014; [3]Invernizzi, Sullivan, Meier, & Swank, 2004; [4]Cabell et al., 2019; [5]Clay, 1979, 2005, 2013; [6]Doyle, 2009; [7]Landry et al., 2017; [8]Justice & Ezell, 2001; [9]Justice et al., 2006; [10] Sheridan et al., 2011; [11]Early Childhood Research Institute on Measuring Growth and Development (1998); [12] Ho, Chan, Tsang, & Lee, 2000; [13] Li, 1999; [14]AIMS Web, 2011; [15]Harcourt Assessment, 2004; [16]Zimmerman et al., 2008; [17] Torgesen, Wagner & Rashotte,1999; [18] Bierman et al. (2018); [19] Good & Kaminski, 2002; [20] Woodcock, McGrew, & Mather, 2001.

Table 2

Mathematical Outcomes and Descriptions

Assessment	Description What is measured?	Reliability (a)
Enumeration and numerical reasoning tasks[1]	Enumeration and numerical reasoning to give a numerical score	NA
TEDI-MATH[2]	Basic maths skills: Number and calculation	.70 and .97[3]
TEMA-3[4]	Measures mathematics performance of children	above .92[4]
Numeral identification task	Identify numbers	NA
Early Number Concepts from the British Ability Scales II (BAS)	The BAS assesses a child's cognitive ability and educational achievement.	.63 to .92[5]

Note. Citations: [1]Starkey et al., 2000; [2] Van Nieuwenhoven, Grégoire, & Noël, 2001; [3] Grégoire, Noel, & Van Nieuwenhoven., 2004; [4] Ginsburg & Baroody, 2003; [5] Elliot, Smith & McCulloch., 2004;

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