A systematic review and meta-analysis of effects of early life non-cognitive skills on academic, psychosocial, cognitive and health outcomes

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Success in school and the labour market relies on more than high intelligence. Associations between ‘non-cognitive’ skills in childhood, such as attention, self-regulation and perseverance, and later outcomes have been widely investigated. In a systematic review of this literature, we screened 9,553 publications, reviewed 554 eligible publications and interpreted results from 222 better-quality publications. Better-quality publications comprised randomized experimental and quasi-experimental intervention studies (EQIs) and observational studies that made reasonable attempts to control confounding. For academic achievement outcomes, there were 26 EQI publications but only 14 were available for meta-analysis, with effects ranging from 0.16 to 0.37 s.d. However, within subdomains, effects were heterogeneous. The 95% prediction interval for literacy was consistent with negative, null and positive effects (−0.13 to 0.79). Similarly, heterogeneous findings were observed for psychosocial, cognitive and language, and health outcomes. Funnel plots of EQIs and observational studies showed asymmetric distributions and potential for small study bias. There is some evidence that non-cognitive skills associate with improved outcomes. However, there is potential for small study and publication bias that may overestimate true effects, and the heterogeneity of effect estimates spanned negative, null and positive effects. The quality of evidence from EQIs underpinning this field is lower than optimal and more than one-third of observational studies made little or no attempt to control confounding. Interventions designed to develop children’s non-cognitive skills could potentially improve outcomes. The interdisciplinary researchers interested in these skills should take a more strategic and rigorous approach to determine which interventions are most effective.

It is over 40 years since economists Bowles and Gintis1, in their critique of the US education system, pointed to the importance of skills for labour market success beyond those captured by intelligence, abstract reasoning and academic achievement in literacy and numeracy. They used the term ‘non-cognitive personality traits’ (p. 116) and pointed to motivation, orientation to authority, internalization of work norms, discipline, temperament and perseverance as characteristics that influenced life success. Although it may be intuitive that there is more to success in life than high intelligence, there has been no attempt to systematically assess the research evidence on the effects of improving different types of non-cognitive skills. We recognize that there is no neat conceptual dichotomy separating cognitive from some non-cognitive skills, but for the purposes of this review, we collectively label the diverse set of factors represented in the literature as ‘non-cognitive’ skills (see Table 1 for a glossary of specific terms). This literature includes studies that either manipulated non-cognitive skills through randomized controlled trials (RCTs) and quasi-experimental designs, or used observed differences in non-cognitive skills through longitudinal or cross-sectional studies. In observational (correlational) data, results from comparing outcomes for higher and lower levels of non-cognitive skills are often used as evidence for their importance in the same way as results from experimental studies.

These non-cognitive skills include attention, executive function, inhibitory control, self-control, self-regulation, effortful control, emotion regulation, delay of gratification and temperament (see Table 1 for our conceptualizations of these constructs). The importance of social skills for labour market success has been demonstrated1, but this review does not directly include improving social skills in early life as a non-cognitive ability, although the range of psychosocial outcomes includes social skill constructs. We sought to provide a systematic representation of research into non-cognitive abilities and behaviours. The need for such a systematic review is driven by the fact that these abilities are being considered by policymakers to underpin early life interventions1, beyond cognitive abilities (intelligence or IQ) and academic achievement (literacy and numeracy).

The policy motivation
This body of research spans disciplines including psychology, sociology, economics, health and education. It is also of great policy interest to governments in many countries1−4, who wish to sustain future economic productivity and social inclusion, by investing substantial resources to bolster the development of human capabilities in early life5, especially for disadvantaged children. The investment logic is that children who develop cognitive and non-cognitive skills early in life have better outcomes later in life. The policy outcomes of most interest are longer term, including labour market success, welfare dependency, social relationships, better mental and physical health that ultimately lead to a more skilled, healthy and productive

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workforce. However, data on the effects of early life cognitive skills on these kinds of later life outcomes are very limited. These generative processes are thought to involve initial investments begetting skills that enable future skills, given sustained investments. Non-cognitive skills, such as being able to sustain attention, may be especially important in this regard because they can scaffold later development of cognitive and non-cognitive abilities. It is argued that, if these skills are not developed early in life, then it can be extremely difficult and expensive to compensate later in life, and this reduces returns on later investments.

**Diversity of non-cognitive skills**

Since 2000, there has been a 400% increase in publications using keywords describing various non-cognitive skills (Supplementary Fig. 1). Several constructs comprise the set of non-cognitive skills reflected in this literature, including academic motivation, responsibility and persistence, temperament, sociability and behaviour problems, locus of control and self-esteem, and attention and socio-emotional skills. Executive functions or control over skills (for example, aspects of how children deploy their cognitive abilities through inhibitory control and attention) may be closely related to cognitive skills, but are also distinguished from IQ, literacy and numeracy. Personality traits, such as self-esteem, patterns of thoughts, feelings and behaviours that include perseverance, motivation, self-control and conscientiousness, have also been considered as non-cognitive or quasi-cognitive characteristics. The term ‘character skills’ has been used to promote the potential malleability of non-cognitive skills in contrast to the notion of personality traits that are thought to be more stable. Heckman and Kautz label these as ‘soft skills’. Despite the conceptual complexity and potential overlap of some constructs, many different non-cognitive or personality or character or soft skills are represented in the literature. They have been the target of interventions, especially in early life when these traits are thought to be especially malleable, and for disadvantaged children, who may benefit most. Interventions to improve non-cognitive skills may directly improve outcomes, or indirectly, through cognitive ability or other mechanisms. For instance, our own longitudinal analyses in three large population-based cohorts in the United Kingdom and Australia showed that both cognitive abilities and non-cognitive skills were important in explaining socioeconomic inequalities in academic achievement early in life and that non-cognitive skills were only weakly associated with cognitive ability.

**Evidence for effects of early non-cognitive skills**

Non-cognitive abilities have been associated with several shorter-term and longer-term outcomes, including mental health, physical health, school readiness and academic achievement, crime, employment and income, and mortality. Evidence from RCTs suggests that preschool interventions that improve school readiness may do so in part by increasing children’s ability to self-regulate their attention, emotion and behaviour. Heckman has...
argued that interventions to develop these skills, especially in disadvantaged young children, have the potential for high rates of return due to their positive effects in multiple life domains.

It is widely accepted that children’s cognitive ability (that is, intelligence or IQ) associates with academic achievement and later success in adulthood. However, the HighScope Perry Preschool Program, which started in 1962, suggests other mechanisms may be involved. The intervention provided an active learning programme based on Piagetian principles, for disadvantaged 3.5-year-old African-American children who had IQ scores on the Stanford Binet Test of <85 (ref. 9). In analysing the long-term outcomes of the trial, Heckman et al. reported that, although initially the intervention increased IQ, these increases were not maintained to 7–8 years of age. Despite this, children who received the intervention went on to enjoy more successful lives in adulthood, including greater labour market success, reduced crime involvement and better health. Although we can find no evidence that the Perry Preschool Program deliberately set out to influence non-cognitive abilities, Heckman and colleagues argued that the intervention resulted in better outcomes for the participants not as a result of increasing their intelligence, but through fostering non-intelligence-based socio-emotional ‘personality’ skills (p. 2,503). It should be noted that the programme also improved maths, reading and language through age 14 and adult literacy, so there may be an array of mechanisms operating through non-cognitive processes as well as IQ and/or aspects of academic achievement. Nevertheless, the argument proposed as to why the Perry Preschool Program ‘worked’ is not dissimilar to the observations of Bowles and Gintis 40 years ago. They argued that interventions to develop these skills, especially in disadvantaged young children, have the potential for high rates of return due to their positive effects in multiple life domains.

We screened eligible publications and report results on associations between non-cognitive skills up to 12 years of age. We grouped publications into four outcome domains—academic achievement (including literacy, numeracy and school readiness), cognitive and language development (including intelligence and language), psychosocial well-being (including mental health problems, such as internalizing and externalizing problems, hyperactivity, social skills and classroom behaviour) and health (including anthropometry and injury). In this paper, we only report results from those publications that we judged to be ‘better’ evidence derived from RCTs and quasi-experimental studies grouped as experimental and quasi-experimental intervention studies (EQIs), and observational studies that made reasonable attempts to control for confounding (endogeneity) bias. However, all eligible publications were fully reviewed and, for completeness, are presented in Supplementary Tables 7 and 8.

Table 2 shows that, of the 554 eligible studies, only 40% (n = 222) were rated as ‘better’ evidence, 21.5% classified as weak and 38.5% as poor, where there was effectively no attempt to control confounding. The better evidence category does not imply that all of the publications in this category would be considered ‘strong’ evidence in terms of their design and analysis. For example, some of the EQIs included in better evidence did not receive high-quality ratings according to the Risk of Bias Tool (Supplementary Table 6). We extracted and reported results separately for EQIs and observational studies that made reasonable attempts to control for confounding (endogeneity) bias. However, all eligible publications were fully reviewed and, for completeness, are presented in Supplementary Tables 7 and 8.
which display all studies in which an effect size and standard error could be calculated.

**Academic achievement outcomes.** Academic achievement outcomes mostly comprised reading, writing and numeracy and were most commonly measured by the Woodcock Johnson psycho-educational battery. For EQIs, Fig. 2a shows that effect sizes ranged from 0.16 s.d. (95% CI: −0.02 to 0.34) for academic achievement and school readiness to 0.37 s.d. (95% CI: 0.16–0.57) for numeracy. The 95% prediction interval for the 11 literacy studies available for meta-analysis was consistent with negative, null and positive effects (−0.13 to 0.79). For observational studies, Fig. 2b shows that effect sizes ranged from 0.16 s.d. (95% CI: 0.12–0.20) for literacy to 0.22 s.d. (95% CI: 0.14–0.31) for academic achievement and school readiness. Prediction intervals were consistent with negative, null and positive effects, ranging from −0.01 to 0.33 for literacy and −0.07 to 0.52 for school readiness. Details of these publications are presented in Supplementary Table 2. Meta-analysis and forest plots are presented in Supplementary Figs. 2a–4b. Supplementary Figs. 24 and 25 graph effect size, age and length of follow-up.

EQIs. There were 26 publications reporting 10 cluster (school or class) RCTs, 11 individual RCTs, 1 study in which the unit of randomization was unclear and 4 quasi-experimental intervention studies. These EQIs involved interventions delivered in usual preschool classes, special classes and groups additional to usual curriculum, at home or a combination of these. Interventions ranged from training specific abilities (for example, executive functions) to interventions that included several components. The interventions included teacher-delivered curricula, teacher training to improve classroom behavioural management and training parents in game-based activities. There was about twice as many EQI publications concerning teacher-delivered curricula than EQIs including both parent and teacher components. The median age at the time of intervention was 4.5 years. The median follow-up time was under 1 year. The oldest age at follow-up was 20 years, from an intervention conducted in 1962, but no effect sizes were reported. The four largest cluster RCTs for literacy and numeracy ranged in effect sizes from 0.09 to 0.49 s.d. (Supplementary Figs. 2a–4b). The individually randomized trials were generally smaller and demonstrated effect sizes up to 0.81 s.d. but were more heterogeneous with a 95%
There were 4 publications of twin studies, 58 longitudinal (including 4 fixed-effects analysis) and 14 cross-sectional publications, with 3 publications reporting results from multiple cohort studies. Non-cognitive abilities were measured at a median age of 5.0 years and a median follow-up of 1.5 years. The oldest age at follow-up was 16 years. Study sizes ranged from 41 to 21,260. The measures of non-cognitive abilities included attention, executive function, inhibitory control, self-control, self-regulation and effortful control assessed via teacher report, parent report and objective tests, such as the Continuous Performance Task, Head Toes Knees Shoulders (HTKS) task and Stroop-like tasks. Effect sizes across observational publications were generally smaller than EQIs. Supplementary Figs. 2a–4b show effect sizes ranging from negative to positive, consistent with negative and positive effects ranging from −0.91 to 1.79.

**Observational.** There were 4 publications of twin studies, 58 longitudinal (including 4 fixed-effects analysis) and 14 cross-sectional publications, with 3 publications reporting results from multiple cohort studies. Non-cognitive abilities were measured at a median age of 5.0 years and a median follow-up of 1.5 years. The oldest age at follow-up was 16 years. Study sizes ranged from 41 to 21,260. The measures of non-cognitive abilities included attention, executive function, inhibitory control, self-control, self-regulation and effortful control assessed via teacher report, parent report and objective tests, such as the Continuous Performance Task, Head Toes Knees Shoulders (HTKS) task and Stroop-like tasks. Effect sizes across observational publications were generally smaller than EQIs. Supplementary Figs. 2a–4b show effect sizes ranging from negative to positive, consistent with negative and positive effects ranging from −0.91 to 1.79.
effects (−0.57 s.d.), to null, to 0.77 s.d. for numeracy and similarly for literacy up to 0.80 s.d. However, 95% prediction intervals were generally narrower than for EQIs (for example, −0.04 to 0.37 for numeracy). There was little evidence to conclude that any one measurement tool, measurement method (objective or subjective) or underlying non-cognitive construct was consistently associated with academic achievement.

Psychosocial outcomes. Psychosocial outcomes included mental health problems (internalizing and externalizing behaviour), social skills and aspects of school readiness, such as learning engagement. For EQIs, Fig. 2a shows that effect sizes ranged from 0.23 s.d. (95% CI: 0.15–0.30) for externalizing behaviour to 0.46 s.d. (95% CI: 0.31–0.61) for social skills. For observational studies, Fig. 2b shows that effect sizes ranged from 0.13 s.d. (95% CI: 0.07–0.18) for social skills to 0.21 s.d. (95% CI: 0.15–0.28) for externalizing behaviour. The 95% prediction interval for psychosocial outcomes was consistent with negative, null and positive effects. For example, the 95% prediction interval for externalizing behaviour was −0.08 to 0.51. Details of these publications are presented in Supplementary Table 3. Meta-analysis and forest plots are presented in Supplementary Figs. 5a–9b. Supplementary Figs. 26 and 27 graph effect size, age and length of follow-up. Studies were not consistent in scoring of psychosocial outcomes, that is, higher scores could indicate worse or better functioning. To aid reader’s interpretation of the results, we have converted all effects to be in the same direction so that positive effects indicate better psychosocial outcomes. However, Supplementary Table 3 presents the results as originally reported in individual publications.

EQIs. There were 32 publications reporting 15 cluster RCTs in classrooms, 12 individual RCTs and 5 quasi-experimental intervention studies in which the intervention was delivered in schools, sports classes, at home or in community-based settings. The content of the interventions was diverse and included teacher-delivered curriculum, sometimes specifically targeting self-regulatory abilities, parent–teacher engagement, teacher training to improve classroom behaviour, training parents in game-based activities, parental motivational interviewing and behaviour management, and marital arts. The median age at the time of intervention was 4.5 years with a median follow-up time of less than 1 year. The oldest age at follow-up was 13.5 years from a non-randomized intervention. Intervention groups ranged in size from $n=16$ to $n=314$ for the individually randomized trials and $n=20$ to $n=-3,350$ for cluster RCTs (the largest RCT did not report the exact intervention number). For externalizing outcomes, the 95% prediction interval for cluster RCTs was 0.10–0.37 s.d. and −0.15 to 0.61 s.d. for individual RCTs. Across RCTs, there was no consistent evidence favouring one mode of intervention delivery over another. The three largest cluster RCTs that trialled well-known interventions (PATHS, ParentCorps and Incredible Years) and had both a teacher and a parent engagement component only reported effects in which $P \leq 0.05$ for 3 of the 11 outcomes studied.

Observational. There were 5 publications of twin studies, 52 longitudinal and 19 cross-sectional publications. The 5 reasonably sized twin studies that combined monozygotic and dizygotic twins ($n$ ranged from 209 to 410 pairs) of children ~2–8 years of age reported phenotypic correlations between non-cognitive abilities and internalizing problems of 0 to −0.3 and −0.1 to −0.6 for fewer externalizing problems. The longitudinal studies ranged in size from 49 to 12,158, and cross-sectional studies ranged from 42 to 2,978. Non-cognitive skills were measured at a median age of 5.0 years with a median follow-up of 8.2 years. The oldest age at follow-up was 19.5 years. Exposures included attention, executive function, inhibitory control, self-regulation, emotion regulation, delay of gratification, effortful control, impulsivity, self-control and temperament, and were assessed by teacher report, parent report and objective tests. Supplementary Figs. 5a–9b show effects from observational studies consistent with ~0.1–0.2 s.d., but all 95% prediction intervals included the null.

Observational studies of psychosocial outcomes were the most heterogeneous in terms of measuring exposures and outcomes, complicating interpretations of overall effect estimates. There was little evidence that attention, executive function and delay of gratification affected psychosocial outcomes. For inhibitory control, self-regulation, emotional regulation, impulsivity, self-control and temperament, there was some evidence of effects (0.1–0.7 s.d.) on social skills and mental health problems. For effortful control, evidence was mixed, ranging from null to 0.85 s.d. on externalizing behaviour.

Cognitive and language outcomes. Cognitive and language outcomes were typically assessed by measures of overall intelligence (such as the Wechsler suite of intelligence tests), verbal and performance intelligence and language development, including expressive and receptive vocabulary (such as the Peabody Picture Vocabulary Test). For EQIs, Fig. 2a shows that the effect sizes ranged from 0.27 s.d. (95% CI: 0.01–0.53) for expressive vocabulary to 0.56 s.d. (95% CI: 0.14–0.99) for general cognitive development. No 95% prediction intervals could be calculated as there were fewer than three studies in each subdomain. For observational studies, Fig. 2b shows that effect sizes ranged from 0.08 s.d. (95% CI: −0.01 to 0.17) for general cognitive development to 0.20 s.d. (95% CI: 0.11–0.30) for total IQ. The 95% prediction interval could only be calculated for receptive vocabulary (−0.17 to 0.50) and general language skills (−0.12 to 0.33). Details of these publications are presented in Supplementary Table 4. Meta-analysis and forest plots are presented in Supplementary Figs. 10a–16b. Supplementary Figs. 28 and 29 graph effect size, age and length of follow-up.

EQIs. There were 23 publications reporting 18 RCTs (2 interventions were reported in 6 publications) and 5 quasi-experimental intervention studies. Of the RCTs, 6 were cluster (school or class) RCTs, 1 in which the unit of randomization was unclear and 11 individual RCTs, involving programmes delivered in schools or classrooms, at home, in a laboratory setting or a combination of classes and home. Three quasi-experimental interventions involved preschool programmes and two involved computerized working memory and inhibitory control training. The content of the interventions was diverse in both delivery and specific focus on non-cognitive ability. Interventions ranged from narrow-focused computer-based training to broader content and delivery by teachers in schools plus home visiting with parents. The median age at intervention was 4.3 years, with a median follow-up of less than 1 year, extending to 16 years. One RCT inconsistently reported effects of 0.15 and 0.25 s.d. on the same language outcome, using the same sample at 5 years of age and an effect of 0.10 s.d. at 6 years of age in a different publication.

Observational. There were 6 publications of twin studies, 14 longitudinal (including one fixed effect) and 9 cross-sectional publications. The 6 twin studies that combined monozygotic and dizygotic twins ($n$ ranged from 40 to 901 pairs) reported phenotypic correlations between non-cognitive abilities and intelligence of ~0.36 to 0.23 s.d. The longitudinal and cross-sectional publications ranged in effect size from ~0.38 s.d. (cross-sectional convenience sample: $n=77$ examining attention) to 0.56 s.d. (cross-sectional convenience sample: $n=80$ examining executive function). Exposure was measured at a median age of 4.5 years. The median duration of follow-up for the longitudinal studies was less than 1 year and the longest follow-up was to 12.4 years. Exposures included attention, executive function, self-regulation, effortful control, inhibitory control and
tremperament, assessed via parent and teacher report questionnaires, such as the Child Behaviour Questionnaire, and objective tests, such as the Continuous Performance Task and the HTKS task. There was no compelling evidence of effects of attention on cognitive and language outcomes from observational studies. For executive function, effects ranged from a detrimental $-0.36$ to $0.52$ s.d., but the evidence is predominantly from convenience samples. There were too few studies to make any judgements about the effects of effortful control and temperament. Most studies of self-regulation used the HTKS task and showed some effects on vocabulary.

**Health outcomes.** There were 2 small RCTs, 1 quasi-experimental intervention, 23 longitudinal and five cross-sectional publications that ranged in size from 105 to >26,000. Details of these publications are presented in Supplementary Table 5. Meta-analysis and forest plots are presented in Supplementary Figs. 17a–19b. Outcomes included anthropometry, injury, diet, substance use and health behaviours.

**EQIs.** There were three publications reporting one cluster RCT, one individual RCT and one quasi-experimental intervention study assessing effects on physical development, teen parenthood and anthropometry. One quasi-experimental study reported an effect of 0.79 s.d., but this effect is difficult to interpret because of an inadequate description of the control group and the outcome. The median age at intervention was 4.4 years. The median follow-up time was less than 1 year, with the oldest age at follow-up of 17 years.

**Observational.** Of the observational studies, the median age at exposure was 9.3 years. The median follow-up time was 4.2 years and the oldest age at follow-up was 55 years. Of the 28 observational studies, 12 involved various outcomes related to substance use, but it is difficult to summarize these because studies either did not report effect sizes or reported unstandardized effects or odds ratios. Observational studies showed little evidence for associations with any of these outcomes.

**Assessment of small study (publication) bias.** The funnel plots in Supplementary Figs. 20a–23b depict effect sizes for experimental and observational studies separately, according to the standard error of the effect size. These include all publications in which effect sizes were reported or able to be calculated, and reported exact $P$ values or $P < 0.05$ (ref. 43). Thus, all studies that reported a $P$ value greater than some threshold were excluded. Funnel plots for both experimental and observational studies were positively skewed and greater than some threshold were excluded. Funnel plots for both outcomes were measured and we grouped them in domains of non-cognitive skills up to 12 years of age on outcomes as they have been presented in the literature. We put no time limit on when outcomes were measured and we grouped them in domains of academic achievement, psychosocial, cognitive and language, and health. This review can say little about longer-term effects that are of central policy interest, such as the effects of non-cognitive skills on labour market experience, because studies eligible for this review do not have data on longer-term outcomes or do not report it. Nor can this review say anything about the importance of non-cognitive skills on later outcomes that are developed as part of normal social interaction and/or the hidden curriculum of more general interventions in which children indirectly develop various non-cognitive skills and behavioural styles.

We were limited to reporting what might be termed ‘proxy’ or ‘intermediate’ outcomes. Although outcomes such as academic achievement are clearly related to employment and labour market experience, this review cannot directly inform the role of non-cognitive ability on important outcomes later in life. Despite the policy enthusiasm and discussion of the importance of non-cognitive skills, the current body of evidence is severely limited given median follow-up periods for EQIs of only about 1 year. We must search elsewhere for evidence on longer-term outcomes because it is precisely in the realm of the labour market that non-cognitive skills may be most beneficial and rewarded.

Overall, there is evidence from published EQIs supporting a role for non-cognitive skills in better academic achievement, psychosocial, and cognitive and language outcomes ranging from approximately 0.2 to 0.5 s.d. depending on outcome as shown in Fig. 2a. We urge some caution in interpreting our results. Analysis of funnel plots clearly demonstrates asymmetry of effect size and the potential of small study bias. In addition, forest plots and 95% prediction intervals show large heterogeneity of reported effect sizes generally including the null. This suggests that the overall meta-analysed effects from EQIs reported here may be overestimates that include a null effect.

Presenting the analysis in Fig. 2 by separating EQIs (Fig. 2a) and observational publications (Fig. 2b) shows larger effects from EQIs than found in higher-quality observational studies, which ranged from approximately 0.06 to 0.22 s.d. This is the opposite of what is often seen, in which observational studies overestimate effects found in large, well-designed RCTs. This overestimation is often due to residual and/or unmeasured confounding introduced by using observations of exposures rather than experimental manipulation of exposures. Furthermore (as pointed out by a reviewer), the effect sizes from EQIs and observational studies would only be comparable if the EQI induced a s.d. change in the particular non-cognitive skill. In reality, effects of interventions on the target non-cognitive skill might be closer to 0.2–0.5 s.d. So, at 0.25 and with no bias, effects found in observational data would be expected to be four-times larger than experimental effects.

Franco et al. found that among rigorously reviewed social science publications in the Time-Sharing in the Social Sciences National Sciences Foundation database, ‘strong’ results were 40 percentage points more likely to be published than null results and 60 percentage points more likely to be written up. They argued that this provided direct evidence of publication bias when researchers choose which results should be written up and presented for publication. It is possible that the published EQIs favour stronger statistically significant results if these are selected by researchers based on $P$ values. If the published EQIs are dominated by smaller studies with lower power, the overall EQI evidence may provide inflated meta-analysed effect estimates. However, we found little evidence of differences in potential small study and publication bias between EQIs and observational studies. Nevertheless, in academic achievement and psychosocial outcome domains, larger sample cluster RCTs tended to generate smaller effects than individually randomized small RCTs. A recent meta-analysis of observational studies of over 14,000 children showed a mean effect size of 0.27 for inhibitory control on academic achievement.
However, this meta-analysis did not exclude poor-quality studies and did not explore potential for small study bias. We deliberately selected higher-quality observational studies with more stringent controls for confounding, so it is possible that true effects of non-cognitive skills are actually closer to those from higher-quality observational studies that may include a null effect.

Main findings. Academic achievement outcomes. Intervention studies focused on improving children’s non-cognitive skills at around 4 years of age with a median follow-up of under 1 year. These studies were generally consistent with 0.2–0.4 s.d. short-term effects on academic achievement, but effects were heterogeneous with 95% prediction intervals including negative, null and positive effects. Larger, higher-quality RCTs showed effects from 0 to 0.3 s.d. These larger, higher-quality RCTs spanned child-focused interventions on specific domains of non-cognitive skills (for example, Tools of the Mind), to more teacher-focused curricula (for example, Chicago School Readiness), to more multidimensional content interventions that included parent, child and teacher (for example, PATHS). Observational studies on academic achievement generally showed effects around 0.2 s.d., but all 95% prediction intervals included the null. This is consistent with one higher-quality observational publication that examined six different cohorts with a longer follow-up of 5.5 years and reported effects from 0 to 0.2 s.d. Overall, there was insufficient evidence on which to base a conclusion about the relative effectiveness of different modes and mechanisms of intervention on non-cognitive skills. Even within the same study, effect sizes differed according to which aspects of academic achievement were measured. For example, one RCT showed an effect on numeracy but not literacy. Similarly, another RCT showed that effects on literacy depended on the component of literacy that was measured and effects on some outcomes faded after 1 year.

Psychosocial outcomes. For psychosocial outcomes, the evidence from RCTs was dominated by studies of externalizing problems, with fewer RCTs on social skills and internalizing problems. The average age at the time of intervention was around 4 years, with a median follow-up time under 1 year. Effects on externalizing problems for EQIs was 0.23 (95% CI: 0.15–0.30), with a 95% prediction interval of 0.07–0.39. Higher-quality RCTs that examined externalizing outcomes reported positive and null effects in the largest of the RCTs. These variable effects could be due to differences in the focus of intervention, mode of delivery (parent, teacher or both) or problems with implementation fidelity in larger trials. Similarly, inconsistent results were reported for EQIs with social skills outcomes. The heterogeneity of effects is mirrored in the twin, longitudinal and cross-sectional studies. A good example of this is the inconsistent results reported in five publications that all used the same data source. Across these five publications, interpretation of the effects of self-regulatory abilities depended on how the exposure (attention, delayed gratification and inhibitory control) and outcome (social skills, withdrawal and aggression) were measured. The different measures of attention had different associations with the same social skills outcome. Inhibitory control was associated with social skills and aggression but not social withdrawal, whereas the effects of delayed gratification on social skills depended on whether the outcomes were directly observed or from maternal report.

The psychosocial outcome studies were the most diverse in interventions (ranging from martial arts to motivational interviewing and Tools of the Mind) and exposure and outcome measurement. This diversity reflected different approaches to improving children’s psychosocial outcomes, such as supporting parents or helping teachers to manage classroom behaviour. Each approach points to different conceptualizations of where psychosocial problems arise and for how, where and whom to intervene (for example, teachers, psychologists, community nurses or social workers).

Cognitive and language outcomes. The relatively small number of studies in this outcome domain (n = 23) produced a wide range of effects. Three reasonably sized cluster RCTs provided the best estimate of the effect of non-cognitive skills on language and cognitive outcomes. They found effects of −0.1–0.2 s.d. The largest effect sizes were from a well-designed regression discontinuity study (0.44 s.d.), a non-randomized intervention (0.55–0.73 s.d.) and a small, low-quality randomized trial. However, all of these studies were small (range: n = 12–64) and reported effects that attenuated over time or were inconsistent at different ages. The observational studies provide little evidence that the effects are likely to be bigger than −0.01 s.d. with 7 of 9 longitudinal studies showing few differences and cross-sectional studies reporting mixed effects (−0.38 to 0.56 s.d.). The longitudinal studies were dominated by non-cognitive skills measured using the HTKS and the Woodcock Johnson Picture Vocabulary as the outcome, and despite the popularity of these measurement tools, the results indicate no effects on vocabulary outcomes. Thus, non-cognitive abilities seem to have effects on cognitive and language outcomes of ≤0.2 s.d.

Physical health outcomes. It is difficult to draw conclusions for physical health outcomes. There were only three EQIs reporting diverse outcomes. Outcomes reported across the 28 better-quality observational studies were diverse, ranging from anthropometry, to injury to physiological characteristics and were consistent with effects ranging from 0.06 to 0.14 s.d.

Limitations of this review. The compilation of 554 publications was systematic, but our assessment of the quality of the evidence is based on our judgement of the potential for bias. Here, we follow the approach of others who have argued for limiting systematic reviews and meta-analyses to higher-quality evidence. We a priori created criteria for bias based on well-established procedures, including quality appraisal tools, evidence hierarchies, directed acyclic graphs and content knowledge about potential sources of confounding and selection bias. Although this involves an element of subjective judgement, we are confident that any other reasonable assessment of the quality of evidence would not change the overall conclusions presented here. In the interests of transparency, we have disclosed all of the subjective choices that we have made in the Supplementary materials and text.

It is possible that some relevant articles were not included in this review, even though we undertook an extensive search that included multiple databases, numerous search terms, contacting authors of potentially relevant papers and handsearching reference lists of published papers. Studies of systematic review methods have shown that the most difficult to find articles are in the ‘grey literature’, sometimes smaller, of poorer quality and the results unlikely to unduly influence the findings in an already large systematic review.

The value of a systematic review. Although there have been reviews of some aspects of non-cognitive skills, none has been systematic in covering the entire literature or included screening for evidence quality. It has long been recognized in health and medical research that non-systematic reviews of research enable the selective use of evidence to support a particular argument. For evidence consumers, who are often not evidence-quality specialists, competing claims about effects of non-cognitive abilities based on particular studies are hard to reconcile without the safety net of a systematic review. We have paid particular attention in this review to issues of quality of the primary evidence. There is little point in summarizing evidence that includes obviously flawed studies that can only distort the overall results and reduce the value of the systematic nature of the review.

This review covers the entire published inter-disciplinary research field, describing intentional efforts and observational analogues
of interventions to improve the development of non-cognitive skills, albeit with most evidence coming from rich countries, especially the United States. The scope of the review should minimize ‘cherry picking’ of results to bolster a particular concept, theory or intervention. This is necessary to advance knowledge given the multidisciplinary nature of this field and is central to informing interventions to boost life chances for disadvantaged children. In health sciences, major advances have been made by coming to agreement and attempting, where possible, to harmonize methods for measuring exposures, outcomes, synthesizing and reporting of outcomes. This work includes collaborative efforts such as the EQUATOR network (http://www.equator-network.org/). Such efforts are needed to reduce waste in research\textsuperscript{66–68} and improve reproducibility of scientific findings\textsuperscript{66–68}.

Implications for future research. What are the active ingredients of non-cognitive skills? Research that has examined non-cognitive skills in childhood has spanned many disciplines and research traditions, leading to a large number of constructs and tasks being investigated that are sometimes similar in their definition and operationalization\textsuperscript{5,6}. In 1927, Kelley labelled this the ‘jangle’ fallacy\textsuperscript{61} (p. 64) in which constructs are given different names but are in fact virtually identical. This idea has been recently raised in regard to the construct validity of the concept of ‘griit\textsuperscript{62}’. It was not uncommon for the same objective tasks to be used as measures of different conceptualizations of non-cognitive abilities. For example, the Continuous Performance Task (also known as the ‘Go/No Go’ task) is used in executive functioning research as a measure of sustained attention and inhibitory control, but it is also used as a measure of effortful control\textsuperscript{63}. Similarly, the HTKS task has been used to measure both behavioural self-regulation\textsuperscript{1} and executive functioning\textsuperscript{7}. The interventions that we reviewed attempted to influence many different facets of non-cognitive skills. Policymakers and researchers ideally need to know what the ‘active ingredients’ are, to enhance children’s non-cognitive skills and, ultimately, the relative effectiveness of different interventions and different intervention doses. There are no strong scientific reasons to favour a specific skill over another, but nevertheless, it remains important to better understand what the active ingredient(s) underlying non-cognitive skills might be, if we want to support their development.

Mechanisms of action. Theoretically, we might expect that interventions involving both parents and teachers might have larger effects on children’s outcomes. However, a recent meta-analysis of early childhood education programmes found little evidence that those with parenting involvement produced larger effects, unless it involved a high dose of home visits\textsuperscript{8}. Of the academic outcomes reviewed here, over half involved only preschool teachers. In our review, there is little evidence to decide which mode of delivery is best and we can find no evidence of attempts at purposive testing of which way to intervene (for example, teacher, student, parent or various combinations). Purposive testing of delivery mode has been usefully deployed in the design of an RCT in regard to the nurse home-visiting literature, showing better effects using trained nurses than using para-professionals\textsuperscript{8}. Interventions that trained children in more specific skills, such as executive function, generally showed small effects (for example, Tools of the Mind\textsuperscript{9}). Other studies imply that non-specific interventions seem to generate better generalized outcomes\textsuperscript{10}, which may suggest that more holistic programmes, including multidimensional content, may better support overall child development and broad-based benefits.

Head-to-head comparisons of interventions. Comparative effectiveness research has been widely promoted in health and medical science as an important contribution to knowing which treatments are the most effective\textsuperscript{27,28}. The potential for interventions on non-cognitive skills to influence outcomes may be enhanced by similar approaches. We could find almost no evidence of these sorts of purposeful comparative studies in this field. Exceptions were Barnett et al.\textsuperscript{49} and Blair and Raver\textsuperscript{29} who examined effects of Tools of the Mind intervention in cluster RCTs and both found effects of ~0.1 s.d. for vocabulary. This exception highlights the potential value of these comparisons.

Designing studies for effect modification. In assessing the potential importance of non-cognitive skills for improving life chances, it is obvious that a combination of both high cognitive and non-cognitive ability would be desirable. If that expectation is correct, then the effects of interest lie in a test of effect measure modification or interaction depending on what effect is of interest\textsuperscript{40}. We found no publications attempting to test this theory, despite its obvious importance for judging how non-cognitive skills might influence later life outcomes. It is also of interest to test for differential effects of developing non-cognitive skills according to different characteristics of children, such as age or socioeconomic background, and of intervention type and setting. However, we urge some caution in investigating differential effects in subgroups when the basic evidence for effects of non-cognitive skills on outcomes, such as academic achievement and psychosocial outcomes, is already highly heterogeneous and consistent with null effects.

Long-term follow-up. There is a paucity of literature with long-term follow-up. Studies typically began at 4–5 years of age, with median follow-up of about 1 year, and with very few studies with follow-up beyond 10 years of age, there is very little evidence addressing effects on medium-to-longer-term outcomes. This is no doubt owing to funding constraints. However, it is frequently argued that non-cognitive skills developed in childhood have major effects on long-term adult outcomes\textsuperscript{2}. Thus, interventions that have short-term effects but few detectable long-term effects are unlikely to be cost-effective. Thus, longer-term follow-up of RCTs is especially important and is being supported by several funding agencies in education and elsewhere. Nevertheless, until such longer-term studies are reported, many of the claims in the literature that early interventions on a specific trait or with a particular intervention have major long-term effects are supported by very little empirical evidence.

Fade out. Recent concerns about the fade out of initially promising effects is crucial to consider in regard to the likely value of interventions early in life. Bailey et al.\textsuperscript{44} argue that interventions should target what they term ‘trifecta skills’ (p. 8). These skills are malleable, fundamental and would not have developed eventually in the absence of the intervention. There were only four studies in which we could assess evidence for fade out and results were inconclusive. This seems another important facet to develop within the research portfolio around non-cognitive skills; studies could be specifically designed to test the fade-out hypothesis in rigorous ways.

Small study effects. Larger effects observed in smaller RCTs may be due to several factors, including publication bias favouring positive results, true heterogeneity of effects due to differing baseline risks in different intervention populations, implementation difficulties in maintaining intervention intensity and fidelity in larger community settings, and poorer methodological design of smaller studies\textsuperscript{41}. If smaller studies were better able to implement the intervention, then larger effects might be real owing to greater fidelity to the intervention as designed. Conversely, publication bias favouring more positive results would mean that larger effects from smaller studies would bias true effects upward. This is an important issue for practice and policy, as it suggests that effects found in RCTs of small convenience samples may be overestimated or even non-existent. For example, when studies are scaled-up, the results can be inconsistent.
or attenuate towards the null, perhaps suggesting that fidelity is harder because an expert is no longer delivering the intervention and/or that larger-scale studies are unable to deliver as intensive interventions as small studies. A useful framework for considering such variation in intervention effects across different scales, contexts and population groups is presented in Weiss et al.82.

**Heterogeneity of effects.** This review clearly demonstrated large between-study heterogeneity from 95% prediction intervals that were consistent with negative, null and positive effects among sub-domains, such as literacy and numeracy. It is possible to argue that this was inevitable in a field in which there are many dimensions of non-cognitive skills being investigated in largely convenience samples, against a wide variety of measures of broad constructs such as literacy and numeracy. Perhaps that is so, but the field is nevertheless presented somewhat monolithically in the application of this science to broad-scale intervention and policy practice. Quantifying the amount of heterogeneity is valuable in providing a baseline from which future research can investigate potential sources of this heterogeneity. For instance, we sought to examine whether studies that used more representative population-based samples tended to generate smaller effect estimates, but the number of population-based samples in this field is actually rather small. For example, of the 11 literacy EQIs that were able to be included in the meta-analysis, only 3 were population based. For externalizing behaviours, of 13 EQIs, only 1 was in a population-based sample.

**Evidence quality. Citing practices.** We reviewed recent RCTs to count the number of previous RCTs they cited. There were seven RCTs published from 2014 to 2016. There were 27 previous RCTs of non-cognitive skills on academic achievement and psychosocial outcome domains available to be cited. The highest number of citations of previous RCTs referenced in any of the RCTs published from 2014 to 2016 was four79. Several RCTs published between 2014 and 2016 referenced no previous RCTs. It could perhaps be argued that these RCTs intervened on different non-cognitive skills, so should not necessarily cite studies of other non-cognitive skills. Nevertheless, attention regulation and self-control were common ingredients of almost all of these interventions (Supplementary Tables 2–5), so the impression is that new RCTs were not being explicitly justified on the basis of what was already known from existing RCTs.

**Quality of RCTs.** The quality of RCTs was not ideal and reporting of some details was poor or even absent. No RCTs had a formal pre-registered protocol and two-thirds did not explicitly identify primary outcomes (See Supplementary Table 6 on Risk of Bias Tool80). This can allow cherry picking of significant results within studies rather than focus on a single or small number of pre-stated main outcome(s) that the intervention is theoretically or empirically (based on previous evidence) meant to most influence. Over one-quarter of RCTs may have had other potential biases, for example, differential participation in the control and intervention groups, and unclear processes for selection of control participants. Ninety-two per cent of RCTs did not adequately report randomization procedures, 81% did not report concealment of allocation processes and participant flow, and most failed to address missing data. It was common for cluster RCTs to have too few clusters to achieve balance between intervention and control groups, and in some, it was unclear whether clustering was adequately dealt with in the analysis. Poor reporting made it difficult to fully assess study quality, and we strongly encourage researchers, journal editors and reviewers to use tools such as the CONSORT statement (http://www.consort-statement.org/) for reporting and for RCTs to be pre-registered. These are now mandatory requirements for publishing in most leading health and medical science journals. However, it is possible that research practice regarding pre-registration is already changing and those pre-registered studies are yet to be published.

**Quality of observational studies.** More than 90% of all research in this field comes from observational studies. Of the 504 observational studies reviewed here, 66% were judged as ‘weak’ or ‘poor’ quality. Of all observational studies, 42% made little or no attempt to adjust for even basic confounding, that is, common causes of non-cognitive ability and the outcome. Problems of endogeneity and confounding are well known and may result in substantial bias of the association of non-cognitive skills and later outcomes.

One regrettable consequence of the relatively low quality of much of the research effort in this field is that it is not able to shed much light on the question of whether improving non-cognitive skills positively influences outcomes. To advance understanding of non-cognitive skills in children and their effects on outcomes later in life, there is little point in amassing more small-scale, biased observational or experimental studies that have a higher likelihood of failing to be replicated and are unable to contribute to evidence triangulation, which is central for stronger causal inference. The recommendations that we make here to improve evidence quality in this field are not controversial. A 2018 Annual Review of Psychology paper called for more sophisticated power analyses, better statistical practices, study design specific to addressing effect modification and better disclosure of non-significant as well as significant findings.

**Implications of suboptimal reporting practices of effect sizes and P values.** To be included in a meta-analysis, studies needed to report or have the information available to calculate an effect size and the standard error. When standard errors were not available, we calculated the standard error from an exact P value, or when the P value was reported as P < p, we assumed that P = p. We were unable to calculate effect sizes in several cases, and in others, P values were reported as P > p. Consistent with recommended practice, this meant that studies were excluded when an effect size and/or a standard error could not be calculated. Excluding studies that reported P > p provides a more conservative estimate of the precision of studies. These exclusions were on top of excluding studies in which an effect size was either not reported or could not be calculated. We illustrate the effect of this two-layer exclusion for literacy outcomes. The literature reported 49 literacy-related outcomes in 17 EQIs. Excluding outcomes in which an effect size could not be calculated reduced the number of available literacy outcomes to 42 outcomes from 14 EQIs. Further excluding results in which the P value was reported as P > p meant that the meta-analysis and funnel plots could only include 33 literacy outcomes from 11 EQIs. Thus, this two-layer exclusion of reported results (owing to suboptimal reporting practices) meant that we could only include 67% of the literacy outcomes actually presented in the literature. This also meant that the meta-analysed effect size for literacy increased from 0.22 (including studies with P > p) to 0.33 (excluding studies with P > p) for EQIs because of the exclusion of studies with smaller effect sizes.

**Interpreting effect sizes.** We have avoided labelling effect sizes as ‘small’ (~0.2 s.d.), ‘medium’ (~0.5 s.d.) or ‘large’ (~0.8 s.d.) according to Cohen’s suggestions. Even though these metrics are widely, often ritualistically, used as reference points, Cohen did not intend them to be used as absolutes. He cautioned that such generic applies of sizes of effects to all research fields was “an operation fraught with many dangers” (p. 12). Deciding whether an effect is ‘big’ is not straightforward in any field. Effect sizes are nothing more than mean differences between intervention (exposed) and control (unexposed) groups on some scale of outcome measurement divided by the standard deviation of the outcome. The use of such standardized effect measures has been criticized in several
consider the size of intervention effects against secular change in an outcome over time. Lipsey et al.\(^\text{52}\) present a sophisticated understanding of interpreting effect sizes. For example, they show that the secular growth in reading from kindergarten to grade one in the United States is estimated to be about 1.5 s.d. By grades 4–5, this growth has declined to about 0.4 s.d. per year. How should an effect of a non-cognitive skills intervention in kindergarten on reading in grade one of 0.2 s.d. be judged? Such an intervention has generated about 13% greater improvement than the natural growth in reading during that time. Deciding whether an intervention is worth implementing will depend not only on its benefits but also on its costs, discount rate, scalability and a range of other potential considerations. Interventions that have small effects on average across the population and that are cheap could be very cost-effective, particularly if they influence long-term outcomes in adulthood. Thus, the traditional labelling of an intervention as having ‘small’ effects (~0.2 s.d.) is inappropriate because it fails to consider the research, policy and practice context within which the intervention is situated.

Conclusion
So, after all the voluminous research included in this systematic review and meta-analysis, do intentional (from EQI evidence) or implied (from observational evidence) efforts to improve early life non-cognitive skills influence outcomes? Overall, yes, there is some evidence supporting a role for non-cognitive skills in better academic achievement, psychosocial, cognitive and language domains, but these effects are highly heterogeneous as they relate to the shorter-term outcomes examined in this review.

We urge caution in interpreting this overall finding as unequivocally positive, given the potential for small study (publication) bias that may overestimate the true effects and the underlying heterogeneity of effect estimates, as shown in 95% prediction intervals that were generally consistent with negative, null and positive effects. Thus, a true null effect of non-cognitive skills on these outcomes cannot be ruled out. We urgently need more robust evidence about which skills may be the active ingredient(s) and which outcomes they affect in the longer term. That may come from studies that are fundamentally free of comparing effects across exposures and outcomes (that is, the difference in s.d. units between intervention and control groups, or the effect of a 1 s.d. increase in exposure on an outcome in observational studies). When unstandardized coefficients were reported, where possible, we calculated standardized effect size to allow comparability of effects across the studies. When a standardized effect size could not be calculated (that is, standard deviations for exposure and outcome were not reported), we reported the unstandardized effect sizes.

Screening to assess risk of bias. The authors J.W.L., L.G.S. and A.C.P.S. reviewed all eligible studies and rated their evidence quality as ‘better, weak or poor’ on the basis of study design and confounding adjustment (Table 2). For example, those already diagnosed with problems such as attention-deficit/hyperactivity disorder) were excluded because we were interested in the effects of non-cognitive characteristics among developmentally normal healthy children.

The inclusion criteria. Publications were eligible if they involved non-cognitive abilities of children up to 12 years of age, including executive function (working memory, cognitive flexibility, inhibitory control and attention), effortful control, emotional regulation (emotional reactivity), persistence, conscientiousness, attention, self-control, impulsivity and delay of gratification. See Table 1 for a glossary of terms. Interventions that had general developmental goals were included if they specifically stated an aim related to improving any non-cognitive abilities. Only publications that reported original research were included. Publications involving non-cognitive characteristics in clinical subgroups (for example, those already diagnosed with problems such as attention-deficit/hyperactivity disorder) were excluded because we were interested in the effects of non-cognitive characteristics among developmentally normal healthy children.

Screening. The titles and abstracts of all articles were screened for eligibility by J.W.L., L.G.S., C.R.C., T.D.S. and N.M.D. To ensure consistent screening, the first 300 references were searched as a group by all authors and subsequent references were searched independently (Kappa values for agreement were >0.80). When eligibility was not able to be determined by the title or abstract, the full text was reviewed, and when eligibility was unclear, this was resolved by group consensus.

Data extraction. The following information was systematically extracted from each article using a standardized form created by the authors. It included: study design, population-based or convenience sample, age of participants at exposure and outcome measurement, sample size and loss to follow-up, measurement of exposure and outcome, type of intervention and comparison group, confounding adjustment and results. To be categorized as a population-based study, the publication needed to report some intent and procedure to sample from a defined population base. For studies that did not report age but did report school grade, ages were approximated on the basis of knowledge of school attendance age in the country of interest. L.G.S., J.W.L., C.R.C., A.C.P.S., T. Goodwin and T. Nuske extracted data from articles. N.M.D. independently (that is, blinded to assessments of other authors) reviewed the data extraction for 15% of all studies, including all intervention studies, and consensus was reached for the very small number of discrepancies.

Where possible, we extracted a standardized ‘beta’ coefficient or standardized effect size to have a unit-free way of comparing effects across exposures and outcomes (that is, the difference in s.d. units between intervention and control groups, or the effect of a 1 s.d. increase in exposure on an outcome in observational studies). When unstandardized coefficients were reported, where possible, we calculated standardized effect size to allow comparability of effects across the studies. When a standardized effect size could not be calculated (that is, standard deviations for exposure and outcome were not reported), we reported the unstandardized effect sizes.

Methods
The systematic review protocol was pre-registered with the International Prospective Register for Systematic Reviews (PROSPERO; CRD42013006566) in December 2013 and is available at: http://www.crd.york.ac.uk/PROSPERO/.
cognitive ability) were rated as better evidence. Here, we only report results from studies that met the definition of ‘better evidence’. However, all weak and poor evidence studies were reviewed and appear in Supplementary Tables 7 and 8.

Data synthesis. Meta-analysis and forest plots. We used effect sizes as reported in the original study or, where possible, used information presented to calculate effect sizes as Hedges’ g. This may mean that some differences exist in how different studies calculated effect sizes in terms of how they included information on standard deviations of the outcome. We synthesized the information on effect sizes by undertaking random effects meta-analysis using inverse variance weighting. When no measure of variance was reported, we calculated confidence intervals from $P$ values. It was common for studies to not report variance or exact $P$ values. To overcome this problem for conducting meta-analyses using inverse variance weighting, we were forced to make assumptions about $P$ values to calculate confidence intervals. If the $P$ value was reported as $P < 0.01$, we assumed $P = 0.01$ for the purpose of calculating confidence intervals. When the $P$ value was reported as greater than a specific value, we followed the Cochrane Review Handbook, which recommends removing any estimates where the $P$ value was reported as greater than some value. The main summary of results is shown in Fig. 2a (EQIs) and Fig. 2b (observational studies). We show the meta-analysed average effect size (and its 95% confidence interval) in each subdomain of academic achievement, psychosocial, cognitive and language, and health outcome. The 95% confidence interval informs how precisely the mean effect size has been estimated. On unlimited repetitions of sampling, and assuming that there is no effect (that is, the null is true), then 95% of all of the confidence intervals calculated would include the true population mean—in this case, the effect size. We also present the 95% prediction interval, which indicates the heterogeneity of effects across the population of studies that generated the meta-analysis effect size. The prediction interval estimates where the true effects are to be expected for 95% of similar studies that might be conducted in the future.

More detailed analyses showing individual publications in each of the subdomains (for example, literacy) are presented in Supplementary Figs. 2a–19b according to study design (EQIs versus observational, and then by cluster, individual, quasi-experimental, longitudinal and cross-sectional). To reduce bias that may have arisen from studies reporting multiple measures of the same outcome, we obtained an overall estimate across all of the reported measures. For example, if a publication reported three different measures of literacy, we meta-analysed those three estimates to get an overall effect. These are the estimates shown in Supplementary Figs. 2a–19b. These figures show the meta-analysed effect size (95% confidence interval), Tau (a measure of variation in true effects among studies), the $P$ statistic, which describes the proportion of observed variability that can be attributed to among-study heterogeneity, and the 95% prediction intervals.

Funnel plots and Egger regression. We examined asymmetry of the published evidence by generating funnel plots of effect size against the inverse of study size separately for EQIs and observational studies (Supplementary Figs. 20a–23b) and calculated the summary Egger regression coefficient and $P$ value indicating the degree of asymmetry. The coefficient from the Egger regression tests whether the $y$ intercept is zero. The expectation is that the $y$ intercept is zero if there is an even spatial spread of studies within the funnel. The coefficient is the effect size normalized by dividing by the standard error ($y$ axis) against the reciprocal of the standard error of the estimate ($x$ axis). Small $P$ values on the Egger regression coefficient suggest the presence of small study bias that may produce larger effects.

Length of follow-up. To include information on the length of follow-up, we graphed each publication according to the length of follow-up, effect size and study size (Supplementary Figs. 24–31). The size of the icon in Supplementary Figs. 24–31 corresponds with small ($n < 100$), medium ($n = 100–500$) and large ($n > 500$) studies. The length of the line displays the duration of follow-up. Supplementary Fig. 32 specifically compares end of intervention (or as closely as we could) with follow-up effect sizes for studies in which it could be calculated.

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability. The data used to undertake this systematic review and meta-analysis are freely available from our BetterStart website (https://health.adelaide.edu.au/betterstart/).

Received: 3 August 2016; Accepted: 28 September 2018; Published online: 5 November 2018

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Acknowledgements

We thank J. Grant, T. Nuske and T. Goodwin for their research assistance in collecting, and initially screening eligibility, and in the preparation of tables and figures. J.L. is funded by a National Health and Medical Research Council of Australia Partnership Project Grant (1056888) and Centre of Research Excellence (1099422). N.D. is supported by the Economics and Social Research Council (ESRC) via a Future Research Leaders Fellowship (ES/N000757/1). The Medical Research Council (MRC) and the University of Bristol fund the MRC Integrative Epidemiology Unit (MC_UU_12013). The funders had no role in study design, data collection and analysis, decision to publish or preparation of the manuscript. All authors will have access to the data and will take responsibility for the integrity and accuracy of the review.

Author contributions

L.G.S., A.C.P.S., C.R.C., G.D.S. and J.W.L. conceived the study. L.G.S., A.C.P.S., C.R.C., G.D.S. and J.W.L. screened the literature and extracted the data. L.G.S., A.C.P.S., C.R.C., G.D.S. and J.W.L. analysed the data. J.W.L. led the drafting of the manuscript, N.M.D. and J.W.L. screened the literature and extracted the data. L.G.S., A.C.P.S., C.R.C., G.D.S. and J.W.L. conceived the study. L.G.S., A.C.P.S., C.R.C., G.D.S. and J.W.L. analysed the data. J.W.L. led the drafting of the manuscript. All authors will have access to the data and will take responsibility for the integrity and accuracy of the review.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information is available for this paper at https://doi.org/10.1038/s41562-018-0461-x.

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Data collection

For this systematic review, the full search strategy including specific search terms and limits applied to search each database for relevant articles has been provided in the Supplementary material. Endnote software (version X7) was used to manage publications retrieved from literature searches. Microsoft Access and Excel (version 2013) were used to extract and collate data from studies included in the review, and excel was used to generate graphs. Effect sizes, prediction intervals, tau statistics, forest plots, funnel plots and Egger regression were conducted using Stata statistical software (SE, version 15).

Data analysis

We used Stata SE program and publicly available syntax for analyses in this study. This included: (1) metan command to generate effect sizes, tau statistics, forest plots and prediction intervals, (2) metafunnel command to generate funnel plots, and (3) metabias command to calculate Egger regression. No custom or open source code was used.

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The methods section of our manuscript has a Data Availability statement where we provide a weblink to the data used for this study (methods section of manuscript). Specifically, we state: "The data used to undertake this systematic review and meta-analysis are freely available from our BetterStart website (https://health.adelaide.edu.au/betterstart)/".

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All studies must disclose on these points even when the disclosure is negative.

| Study description | This article reports a systematic review and meta-analyses. The data are quantitative. |
|-------------------|-----------------------------------------------------------------------------------|
| Research sample   | All studies that had samples involving typically-developing children were eligible to be included in the review. The review was limited to children aged 12 years and under at the time of intervention or exposure, with no age limit posed on the age at follow-up. Studies with convenience samples and population-based samples were included in the review. |
| Sampling strategy | Eligible studies were sampled via database searches (Pubmed, PsycINFO, Embase and Business Source Complete) as well as through searching reference lists of reviews on the topic, references lists of randomised controlled trials that were included in the review, and our own libraries. As we intended to review all available literature on the topic, no predetermined sample size calculation was conducted. |
| Data collection   | Data collection proceeded electronically, via searches of electronic databases for eligible articles and storage of articles in Endnote libraries. Extraction of data from articles included in the review was via a Microsoft access database and an Excel spreadsheet. Blinding was not undertaken during implementation of the review procedures as it is impractical to blind the researchers who extracted data from published articles. |
| Timing            | Articles were eligible to be included in the review if they were published on or before December 2016. |
| Data exclusions   | Articles published in other languages for which there was no English translation or published after December 2016 were excluded. Some studies were unable to be included in the meta-analyses if they did not report effect sizes and standard errors or reported p values greater than some value (e.g. p>0.05). |
| Non-participation | Where available, details of follow up (attrition) are given in the Supplementary Material. Not all studies reported this information. |
| Randomization     | No randomisation occurred as part of the review. Details of randomisation procedures within each randomised controlled trial that was included in the review are provided in the Supplementary Material. |

Reporting for specific materials, systems and methods

| Materials & experimental systems | Methods |
|---------------------------------|---------|
| n/a                             | n/a     |
| ☒ Unique biological materials  | ☒ ChiP-seq |
| ☒ Antibodies                   | ☒ Flow cytometry |
| ☒ Eukaryotic cell lines        | ☒ MRI-based neuroimaging |
| ☒ Palaeontology                |         |
| ☒ Animals and other organisms  |         |
| ☒ Human research participants  |         |