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The Role of Executive Functions in Socioeconomic Attainment Gaps: Results From a Randomized Controlled Trial

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Abstract

The socioeconomic attainment gap in mathematics starts early and increases over time. This study aimed to examine why this gap exists. Four-year-olds from diverse backgrounds were randomly allocated to a brief intervention designed to improve executive functions (N = 87) or to an active control group (N = 88). The study was preregistered and followed CONSORT guidelines. Executive functions and mathematical skills were measured at baseline, 1 week, 3 months, 6 months, and 1 year posttraining. Executive functions mediated the relation between socioeconomic status and mathematical skills. Children improved over training, but this did not transfer to untrained executive functions or mathematics. Executive functions may explain socioeconomic attainment gaps, but cognitive training directly targeting executive functions is not an effective way to narrow this gap.

The socioeconomic attainment gap in mathematical skills starts early in development and widens over time (Rathbun & West, 2004; Starkey & Klein, 2008). Children from disadvantaged backgrounds arrive in school less prepared to learn, placing them at long-term academic risk (Jordan & Levine, 2009). Mathematical skills are a strong predictor of overall attainment, and of health, wealth, and socioeconomic status (SES) in adulthood (Berkman, Sheridan, Donahue, Halpern, & Crotty, 2011; Ritchie & Bates, 2013; Rivera-Batiz, 1992). Therefore, to ensure that early attainment gaps do not perpetuate the cycle of inequality, it is important to understand the pathways by which SES is associated with mathematical skills early in development. By doing this, we can design and test interventions to help narrow the gap. In this study, we first examine whether executive functions mediate the relation between SES and mathematical skills in preschoolers. We then causally test whether executive functions mediate this gap by examining whether an executive function training intervention following a randomized control trial (RCT) design can help to narrow the attainment gap.

SES refers to an individual or family's access to economic and social resources, and the privileges, prestige, and social positioning that derive from these resources (Duncan & Magnuson, 2012). Children from low-SES backgrounds tend to have poorer health, cognitive skills, and academic attainment (Bradley & Corwyn, 2002; Noble, McCandliss, & Farah, 2007). SES is thought to operate at multiple levels to affect outcomes in childhood, and as

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such can be measured in several ways through household income, parent education, and family neighborhood (Leventhal & Brooks-Gunn, 2000). All these indicators have been associated with health, cognitive and academic outcomes (Adler & Snibbe, 2003). For example, family neighborhood is associated with these outcomes, even when individual-level SES such as income and education are controlled for (Bradley & Corwyn, 2002).

One early and persistent difference that arises between higher SES children and lower SES children is in the domain of mathematical skills. Lower SES children tend to begin school with less mathematical knowledge and skills than their higher SES peers, and this gap widens over the first 4 years of school (Rathbun & West, 2004). Mathematics is a subject in which early skills set a foundation for more advanced concepts (Morgan, Farkas, & Wu, 2009). This may explain why attainment gaps widen over time, as having poor foundational mathematical skills limits opportunities for further learning (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004). SES may have *direct* pathways to mathematical skills, as lower SES children may receive less exposure to mathematical learning opportunities, numerical concepts, or number talk (Elliott & Bachman, 2018). It is also possible that attainment gaps may be driven by *indirect* pathways, through the effect SES may have on the cognitive skills that underpin mathematical skills (Lawson & Farah, 2017). Given that mathematical skills at school entry predict attainment through school (Duncan et al., 2007), it is important that mediators of this relationship are identified so that early interventions can be developed and rigorously tested.

One potential cognitive mediator of the SES-mathematical skills relation is executive functions. A large body of research has found links between mathematical skills and executive functions (Blair & Razza, 2007; Bull & Scerif, 2001; Gathercole & Pickering, 2000). Executive functions are domain-general cognitive skills that exert top-down control over attention and behavior (Diamond, 2013). Executive functions include working memory, which allows us to maintain and process information; inhibitory control, which allows us to suppress automatic but incorrect responses; and cognitive flexibility, which allows us to adjust our behavior according to changes in the environment or our goals (Miyake et al., 2000). In early childhood, these three executive functions are thought to comprise a single latent factor (Wiebe, Espy, & Charak, 2008). Executive functions show protracted development over childhood, but rapid developments occur during the preschool years (Garon, Bryson, & Smith, 2008) and their role in the regulation of behavior is particularly important in the transition to formal schooling, when children are required to sit still, pay attention, and follow instructions (McClelland & Cameron, 2012). While executive functions support learning more generally, working memory and inhibitory control have been strongly related to mathematical skills, perhaps because mathematical thinking often involves maintaining large amounts of information, ignoring distracting information and suppressing automatic but incorrect strategies (Blair, Ursache, Greenberg, Vernon-Feagans, & The Family Life Project Investigators, 2015; Cragg & Gilmore, 2014). Indeed, influential accounts of mathematical development tend to include both domain-specific skills and domain-general skills, with a specific emphasis on executive functions. Executive function skills are seen as a pathway to early mathematical development (LeFevre et al., 2010), or as vital in supporting domain-specific numeracy skills including conceptual understanding and procedural skills (Geary, 2004).

We propose that one pathway through which SES may influence mathematical skills is executive functions. Not only do executive functions support mathematical skills, but there is also emerging evidence that SES has a specific effect on executive functions—more so than basic cognitive skills such as short-term memory and visual processing (Farah et al., 2006; Hackman & Farah, 2009; Lawson, Hook, & Farah, 2018). SES may exert effects specifically on executive functions because of their protracted development, which makes them susceptible to environmental effects (Hackman, Farah, & Meaney, 2010). While there is emerging evidence demonstrating links between SES and executive functions, theoretical accounts to explain this specific relation are limited at present. Possible environmental effects that may impact executive functions and may also relate to SES include parental responsiveness (Devine, Bignardi, & Hughes, 2016), maternal and child language (Daneri, Blair, Kuhn, & FLP Key Investigators, 2018), and stress (Blair & Raver, 2015). Parenting is likely to be a key mechanism through which social inequality influences very early development, as during this time, children are particularly dependent on their caregivers for stimulation, nurture and regulation (Fay-Stammbach, Hawes, & Meredith, 2014). High-quality parent–child interactions often involve rich language input and parent–child scaffolding—two domains that have been especially linked with executive function development

(Gooch, Thompson, Nash, Snowling, & Hulme, 2016; Hughes & Ensor, 2009).

While there is growing evidence that SES is associated with executive function development, research examining the possible mediating effect of SES on academic attainment *via* cognition is scarce. There have been a handful of studies that have helped to elucidate the relation between children's executive functions, SES, and mathematical skills (Dilworth-Bart, 2012; Fitzpatrick, McKinnon, Blair, & Willoughby, 2014; Lawson & Farah, 2017; Nesbitt, Baker-Ward, & Willoughby, 2013; Sektnan, McClelland, Acock, & Morrison, 2010). These studies have demonstrated an important role of executive functions in mediating SES attainment gaps in mathematics. However, few of these studies have focused on preschoolers, who are yet to start formal schooling and whose executive functions are rapidly developing. Of the studies that have focused on preschoolers, they have tended to rely on crude measures of SES (such as whether children attend private school with a Montessori curriculum, or a needs-based school) or have not examined executive functions as a latent factor to minimize error variance (Fitzpatrick et al., 2014). Others have had modest samples which limit the types of models that can be run, or have worked with mostly middle-class children (Dilworth-Bart, 2012). Therefore, at present we can only draw limited conclusions regarding the extent to which executive functions mediate mathematical attainment gaps in socially diverse preschoolers.

If executive functions do mediate the relation between SES and mathematical skills, it would suggest that interventions to narrow the attainment gap should focus on improving executive functions *early* in development. It has been proposed that early development may be the optimal time to intervene, before any negative effects fully embed (Heckman, 2006; Ramey & Ramey, 1998). A common approach to improving children's executive functions has been through cognitive training programs which directly target specific executive functions (Kassai, Futo, Demetrovics, & Takacs, 2019). Meta-analyses of studies with adults and older children indicate that training that targets working memory and inhibitory control can lead to improvements on trained constructs—so-called "near transfer"—but does not lead to improvements on untrained constructs, or "far transfer" (Kassai et al., 2019; Melby-Lervåg & Hulme, 2013; Sala & Gobet, 2017; Schwaighofer, Fischer, & Buhner, 2015). However, the evidence with younger children is still mixed, with some recent studies showing transfer of training to mathematical skills (Jones, Milton, Mostazir, & Adlam, 2019). In addition, the few studies that have been carried out with younger children (Thorell, Lindqvist, Bergman, Bohlin, & Klingberg, 2008; Wass, Cook, & Clackson, 2017; Wass, Porayska-Pomsta, & Johnson, 2011) and with young *and* diverse samples (Ballieux et al., 2016; Goldin et al., 2014) have showed promising results. Indeed, a meta-analysis of cognitive training studies concluded that training is more likely to lead to far transfer in younger participants than in older participants (Wass, Scerif, & Johnson, 2012), perhaps because the neural networks underpinning executive functions are undifferentiated earlier in development (Karmiloff-Smith, 1998). Despite this, few cognitive training studies have focused on the preschool years; even fewer have examined whether training effectiveness interacts with a child's SES.

This study had three aims: firstly, to determine whether differences in executive function skills can explain the SES attainment gap in early mathematical skills; secondly, to test this prediction causally by establishing whether a brief, four-session executive function training intervention can improve both executive functions and mathematical skills in preschoolers; and thirdly, to examine whether the training program would be more effective for children from lower SES backgrounds than children from higher SES backgrounds, thereby helping to narrow the attainment gap between these groups. This is the first study to examine whether executive function skills mediate the attainment gap in mathematics seen between preschoolers from lower and higher SES backgrounds, and to test this causally by running a RCT designed to improve executive functions.

To address the first aim of the study, we used structural equation modelling (SEM) to test our prediction that executive functions mediate the relation between SES and mathematical skills. The use of SEM allowed us to derive latent factors representing executive functions. Latent factors capture shared variance between indicators of an underlying construct to reduce measurement error (Kline, 2011).

To address the second aim of the study, we ran an RCT to test whether a brief executive function training intervention would improve both executive functions and mathematical skills in preschoolers. The intervention was based on a previous design tested on a smaller scale that found improvements in working memory for 4-year-olds from mid-SES backgrounds (Blakey & Carroll, 2015). Several methodological issues have been identified with existing training studies that we considered in the present study. Specifically, many existing studies do not follow CONSORT guidelines, have small sample sizes, do not have experimenters blind to the child's condition, and do not use active control groups. Furthermore, few studies assess transfer over time, or transfer to tasks that are very different to the trained tasks. These issues mean we cannot be sure that training is indeed improving the targeted construct, rather than simply offering practice on specific tasks (see Melby-Lervåg, Redick, & Hulme, 2016; Shipstead, Redick, & Engle, 2012, for a discussion of these issues). Moreover, training studies often require a lot of time and investment, and educators are keen to know if these are a solution for helping children in the classroom. Therefore, it is vital that studies testing their effectiveness are designed in a way that allows us to draw robust conclusions. In this study, therefore, we compared our intervention to an active control group with a sample size powered to detect an effect of training; the study was preregistered and followed CONSORT guidelines; and we examined transfer to very different, nontrained tasks up to 1 year later, with experimenters blind to condition. Based on the transfer to working memory found in a smaller scale version of this intervention (Blakey & Carroll, 2015) and the previous studies that have shown transfer in preschoolers (e.g., Thorell et al., 2008), we predicted that the intervention would improve working memory, and we further aimed to explore if this improvement would transfer to mathematical skills.

The intervention was designed to be brief, for several reasons. Firstly, for lower SES children, attendance in lessons is crucial for academic success (Sylva, Melhuish, Sammons, Siraj-Blatchford, & Taggart, 2011), and so it is important that interventions do not take children out of the classroom for extended periods. Secondly, brief cognitive interventions with as few as three sessions have been administered with infants and toddlers and have shown transfer, suggesting that brief training interventions can be effective (Wass et al., 2011, 2017). Finally, the duration of training has been shown to have little impact on the extent of transfer (Karbach & Verhaeghen, 2014; Melby-Lervåg et al., 2016; Sala & Gobet, 2017), suggesting that shorter training interventions should be prioritized, as their relative brevity means they are more likely than longer interventions to be widely implemented.

To address the third aim of the study—examining whether training would be more effective for children from lower SES backgrounds than children from higher SES backgrounds—we examined whether training effectiveness interacted with SES. We predicted that the intervention would be more beneficial to children from lower SES backgrounds (who typically have poorer executive functions). We based this hypothesis on the idea of compensatory effects (Titz & Karbach, 2014): that high-performing individuals, who tend to be higher SES children, would benefit less from cognitive interventions because they are performing nearer to their personal ceiling. On the assumption that environmental effects may explain the social gradient, we hypothesized that providing extra practice in using executive functions could benefit those for whom the environmental effects had not already reached ceiling.

Preschoolers from high- and low-SES neighborhoods first completed baseline measures of executive function, mathematical skills, and vocabulary. They were then randomly allocated to either an executive function training group or an active control group. The training program targeted working memory and inhibitory control—two core executive functions in early childhood (Chevalier et al., 2012; Garon et al., 2008) that have been found to consistently relate to children's foundational mathematical skills (Cragg & Gilmore, 2014; Ragubar, Barnes, & Hecht, 2010). The baseline tasks were repeated at posttest and at follow-ups over 1 year, enabling us to examine if any transfer was maintained over a longer period of time.

Method

Participants

Initially, 196 three- to four-year-olds were recruited from eight preschools in socioeconomically diverse areas of South Yorkshire, UK—see Figure 1 for the CONSORT diagram showing the flow of participants through the study. A power calculation indicated that 156 children would be required to detect a small-medium (.40) one-tailed effect in favor of the intervention, with a power of .80 and alpha .05. We therefore aimed to recruit 195 children to allow for 20% attrition.

Inclusion criteria were that children were typically developing; that children spoke and understood English (judged by teachers); that children were due to start formal schooling the next academic year; and that children were in a nursery school attached to, or near, the primary school that they would attend in future (to facilitate follow-up

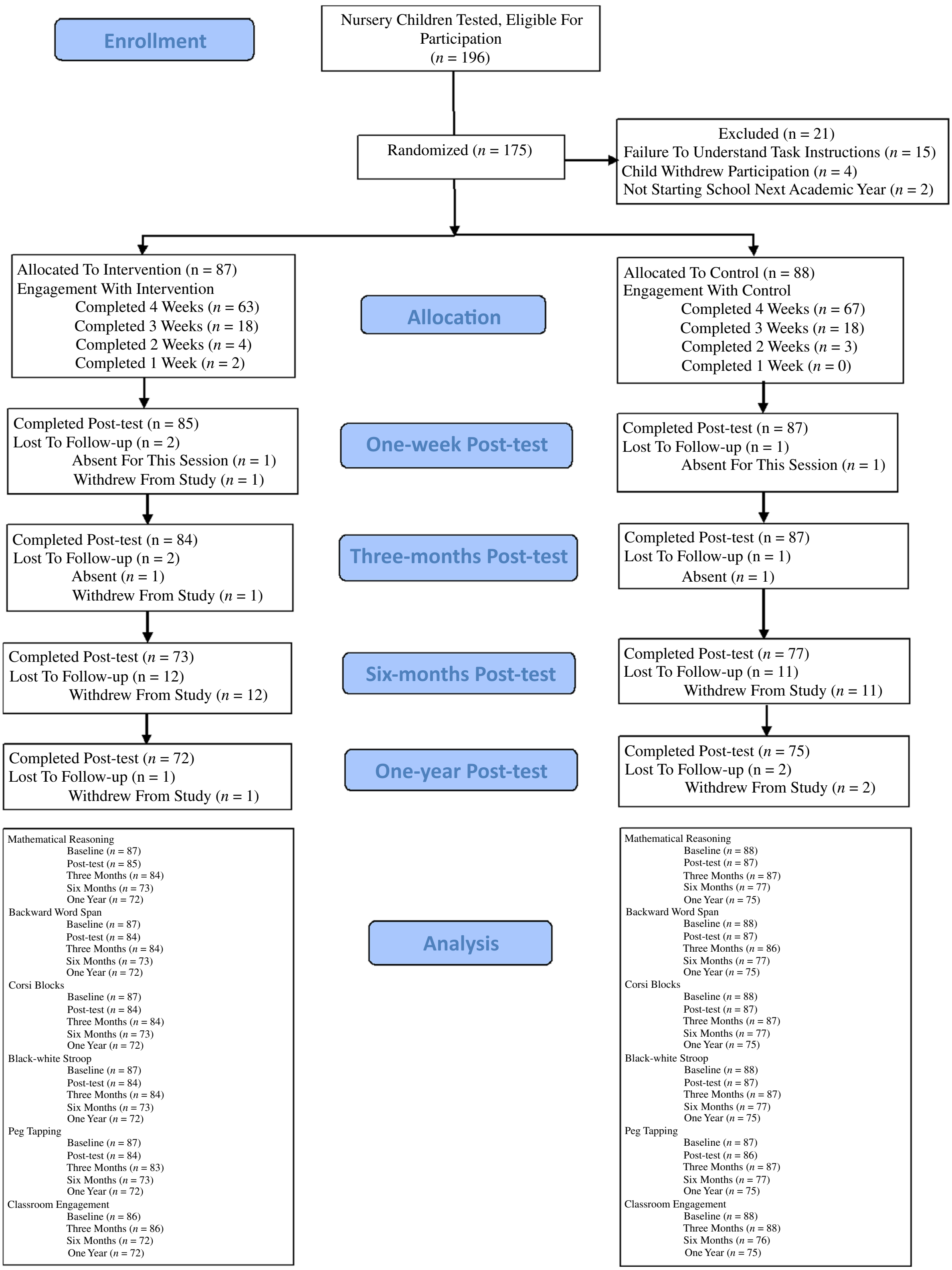

Figure 1. Flow of participants through the study.

testing). The final sample comprised 175 children (M_{age} = 48 months, range = 39–54 months; 78 males, 97 females), randomly allocated to the training group (N = 87, M_{age} = 48 months, SD = 3.64; 45 males, 42 females) or the control group (N = 88, M_{age} = 48 months, SD = 3.85; 33 males, 55 females).

We used the Index of Multiple Deprivation (IMD) as a measure of children's SES. The IMD is a precise index of SES that measures relative neighborhood deprivation (at a street–by-street level), provided by the UK Office for National Statistics (English Indices of Deprivation, 2015) for each of the 32,844 neighborhoods in England. The IMD is calculated using the following indicators of SES: employment; income; education and skills; health and disability; health provision; crime; barriers to housing and services; and the living environment. We calculated each child's SES based on their home postcode where possible (71% of children), or where this information could not be obtained, based on their school's postcode (29% of children). In this latter case, this was a good estimate, as according to IMD maps, the nursery catchment areas were homogeneous in terms of distribution of IMD, making this measure an accurate measure of SES. While the IMD deciles spanned the full range from 1 to 10, the scores were bimodal, with 59% of children in the lowest three deciles and 35% in the highest three deciles. Only 7% of children were in deciles 4–7. Therefore, children were categorized as low-SES if they lived in deciles 1–4 (N = 108) and high-SES (N = 67) if they lived in deciles 5–10. The two intervention groups had comparable SES profiles: in the training group, 55 children were from low-SES backgrounds and 32 children were from high-SES backgrounds, whereas in the control group, 53 children were from low-SES backgrounds and 35 children were from high-SES backgrounds.

We sought to obtain parental education information via a questionnaire sent out to parents. Questionnaires were returned by 67% of parents. Each main caregiver's highest educational qualification was scored from 1 to 7 according to the following educational categories (highest to lowest): postgraduate degree (21% of parents), undergraduate degree (23%), foundation degree (3%), A-levels or BTEC awards (20%), GCSEs A*-C or NVQs (21%), GCSEs grades D-G (7%), or entry level skills (7%). Parents in the high-SES IMD group were significantly more likely to have a higher educational qualification (M = 5.71, SD = 1.59) than parents in the low-SES IMD group (M = 2.67, SD = 1.94), $t(109) = -8.93$, $p < .001$. However, these education data were Missing Not at Random, as families in the high-SES group (76% return rate) were significantly more likely to return the questionnaire than families in the low-SES group (61% return rate), $\chi^2(N = 175) = 4.20$, $p = .04$. Therefore, this information is reported as descriptive information only.

Design

This study used a RCT with a pretest–posttest design following CONSORT guidelines (see the Appendix S1, for the CONSORT checklist). The RCT was preregistered at clinicaltrials.gov (ID: NCT03063411). Recruitment started in January 2017 and testing took place between March 2017 and April 2018 when the 1-year follow-ups were complete. Children first completed baseline measures of mathematical skills and executive functions. Participants were then randomly assigned to either the executive function training group or the active control group, with the sole constraint that children from each of the eight participating preschools were distributed equally across the two groups. The random assignment was administered by someone from outside of the project using a random number generator. Children in both groups completed computerized tasks lasting 20 min, once a week for 4 weeks. Baseline measures of executive functions and mathematical skills were re-administered by experimenters, blind to the child's group, at four separate time points: 1 week posttraining, 3 months posttraining, 6 months posttraining, and 1 year posttraining. A measure of receptive vocabulary was included at baseline. In addition, to examine if training transferred to classroom behavior, teachers rated children's classroom engagement at baseline and then again at 3 months, 6 months, and 1 year posttraining. Teachers and parents were blind to the child's group. The study received ethical approval from the University's Psychology ethics subcommittee. Children received a sticker for their participation at each session, and each class received a small class gift when testing was complete. Teachers received a £1 gift voucher for each classroom engagement scale they completed.

Procedure and Materials

Children were tested individually in their preschool. To help to ensure the fidelity of the intervention, children completed each intervention session one-on-one with a trained research assistant. All training and control tasks were administered on a Dell XPS 12-9250 touchscreen laptop running E-Prime software (Psychology Software Tools, Pittsburgh, PA). To reduce incidental between-group differences, similar stimuli were used in the training and control tasks, and feedback was provided in all tasks for both groups.

Training Tasks

Four tasks were used as part of the training program, adapted from established measures of preschool executive function. The training program was based on a prior study showing transfer to working memory in a mid-SES sample of children (Blakey & Carroll, 2015). Two tasks involved working memory: The Six Boxes task (Diamond, Prevor, Callender, & Druin, 1997) and the One-back task (Tsujimoto, Kuwajima, & Sawaguchi, 2007); and two tasks involved inhibitory control: interference control (the Flanker task, Rueda, Posner, & Rothbart, 2005) and response inhibition (the Go-No-Go task, Simpson & Riggs, 2006). Children completed all four tasks in a single session, and each task lasted approximately 5 min. Tasks were adaptive: they increased in difficulty the following session if children were accurate on 75% or more of trials. Tasks were administered in the same order: the Six Boxes task, followed by the Flanker task, the One-back task, and the Go-No-Go task.

Working memory training tasks. In the Six Boxes task, children found rewards (e.g., stickers) hidden behind six different objects (e.g., colored boxes). To begin with, all of the objects hid a reward. Thus, on the first turn, searching behind any object would reveal a reward. Subsequently, children needed to remember which objects they had already searched behind in order to avoid returning to these—now empty—locations. If children did return to objects from which they had already retrieved a sticker, an empty box was revealed, and this was counted as an error. Objects were rearranged between trials. Children completed this task twice consecutively in each session. The game ended either when children had found all the rewards, or after 16 trials. The dependent variable was the number of trials taken to find all items. In the first training session, the inter stimulus interval (ISI) was 4,000 ms. The ISI increased by 2,000 ms (to a maximum of 8,000 ms) if children scored 75% or more correct in the previous session. In the One-back task, children were shown a succession of images (e.g., animals), presented one at a time for 2,000 ms each. Children were told to touch the image on the screen if it matched the image that had appeared on the preceding trial. Children completed three blocks of 20 trials (of which one third were "hit trials" in which the image shown had also appeared on the previous trial). The dependent variable was total accuracy. In the first training session, the ISI was 1,000 ms. The ISI duration increased by 1,000 ms (to a maximum of 3,000 ms) if children scored 75% or more correct in the previous session.

Inhibitory control training tasks. In the Flanker task, children were presented with a line of five stimuli (e.g., rockets), and pressed an arrow at the bottom of the screen to indicate which direction the central stimulus was facing (left or right). Children completed three blocks of 20 test trials. Half the trials were congruent (stimuli were all left-facing or all right-facing); and half were incongruent (the middle stimulus faced the opposite direction to the flanking stimuli). Stimuli were presented for 4,000 ms, with an ISI of 1,000 ms. If children were accurate on 75% or more of trials, the amount of time that stimuli appeared on the screen in the next session was reduced by 1,000 ms (to a minimum of 2,000 ms). In the Go-No-Go task, children were required to touch a series of stimuli appearing on the screen (e.g., a colorful fish) but to make no response when a specific "no-go" stimulus appeared (e.g., a shark). Children completed three blocks of 20 test trials (Go:No-go trial ratio 2:1). In the first session the stimuli appeared on screen for 2,500 ms. If children were accurate on 75% or more of no-go trials, this time reduced by 500 ms (to a minimum of 1,500 ms).

The Active Control Group

The control group completed three tasks that required children to make simple perceptual judgments. The first task required children to decide whether two pictures were the same or different; the second task required children to make simple conceptual or perceptual decisions around different pictures (e.g., "Press the animal that can fly"); and the third task required children to search for a particular image among distractors (e.g., "Find the cat in the tree"). The control tasks used the same stimuli and lasted the same duration as the training tasks.

Outcome Measures: Baseline and Posttest Tasks

To assess training improvements to mathematical skills and executive functions, different, nontrained tasks were administered at baseline and posttest by an experimenter blind to the child's group. The executive function tasks were chosen because they did not share the same surface features or instructions as training tasks. Tasks were administered in the following fixed order: the Backward Word Span, the Peg-tapping task, the Corsi Block task, the Black–White Stroop task, and the Mathematical Reasoning task. When receptive vocabulary was measured at baseline only, it was assessed last.

The Backward Word Span task was used to assess working memory (Davis & Pratt, 1996). Children were shown pictures of familiar objects one at a time (e.g., a tree, then a hat) and were asked to recall them in a backward order. Children completed two practice trials, and then up to 12 experimental trials, three of each span (two, three, four, and five). If children got at least two out of three trials correct, the span length increased. The dependent variable was the total number of trials correctly recalled in a backward order. The task has been shown to have moderate-good test–retest reliability in preschoolers (intraclass coefficient [ICC]: .67; Müller, Kerns, & Konkin, 2012).

The Corsi Block task was used to assess visuospatial short-term memory (Corsi, 1972). Children were presented with a tray consisting of nine blocks in fixed locations. Children were asked to repeat the sequence of blocks tapped by the experimenter. Children completed two practice trials, and then up to 12 experimental trials, three of each span (two, three, four, and five). If children got at least two out of three trials correct, the span length increased. The dependent variable was the total number of trials correctly repeated. The task has been shown to have excellent test–retest reliability in children (ICC: .90; Alloway & Passolunghi, 2011).

The Peg Tapping task was used to measure inhibitory control (Diamond & Taylor, 1996). Children were instructed to tap twice with a peg when the experimenter tapped once; and to tap once when the experimenter tapped twice. After watching a demonstration, children completed 12 trials in a pseudorandom order (six of each rule, with no more than three consecutive trials of the same rule). The dependent variable was the number of correct responses. The task has been shown to have excellent test–retest reliability in children (ICC: .93; Karalunas, Bierman, & Huang-Pollock, 2016).

The Black–White Stroop task (Gerstadt, Hong, & Diamond, 1994) was used as a second measure of inhibitory control. Children were instructed to point to the Black card when the experimenter said "White" and to point to the White card when the experimenter said "Black." After watching a demonstration, children completed 12 trials in a fixed pseudorandom order (six of each rule, with no more than three consecutive trials of the same rule). The dependent variable was the number of correct responses. Test–retest reliability scores are not available for this specific variant with black and white cards, but a version of the same task using pictures of faces showed good reliability (ICC: .86; Lagattuta, Sayfan, & Monsour, 2011).

The Mathematical Reasoning subtest of the Wechsler Individual Achievement Test-II battery was used to measure mathematical skills (Wechsler, 2005). The Mathematical Reasoning subtest is a reliable and standardized broad measure of mathematical skills. It comprised 30 questions assessing children's ability to identify numbers, to count, to extract information, and to solve numerical word problems. Testing was discontinued after six consecutive incorrect responses. The dependent variable was the number of correct responses. This was our primary outcome measure.

The Receptive Vocabulary subtest of the Wechsler Individual Achievement Test-II battery was used to measure vocabulary (Wechsler, 2005). This reliable and standardized task comprised 16 questions assessing children's ability to identify which of four images matched a spoken word. The task was discontinued after six consecutive incorrect responses. The dependent variable was the number of correct responses.

The Classroom Engagement Scale (adapted from Pagani, Fitzpatrick, Barnett, & Dubow, 2010) was used to assess children's classroom behavior. A teacher blind to the child's group rated each child using the questionnaire at baseline, 3 months, 6 months, and at 1 year posttest. Items were rated using a scale of 1 (*never*), 2 (*sometimes*) and 3 (*always*). Teachers rated the extent to which children followed rules and instructions, followed directions, listened attentively, worked autonomously, worked and played cooperatively with other children, and worked neatly and carefully. The dependent variable was the sum score of the six items.

Results

Relations Between SES, Executive Functions, and Mathematical Attainment at Baseline

We first examined relations between SES, executive functions, and mathematical skills. Table 1 shows the correlations among all measures at baseline. All executive function tasks were positively correlated with each other, and with mathematical skills. Correlations at follow-up are given in

Supporting Information (they show a pattern similar to that seen at baseline). Table 2 shows differences in executive functions and mathematical skills between children from high- and low-SES backgrounds. In line with Hackman and Farah (2009), SES differences in performance were found in tasks with higher executive function demands. SES had a medium-to-large association with inhibitory control, a small-to-medium association with working memory, and very small associations with visuospatial memory and vocabulary. In addition, SES had a medium association with mathematical skills. Data from follow-up are presented in Supporting Information and show a pattern similar to that seen at baseline. Interestingly, the associations between SES and mathematical skills, and between SES and working memory increase and become medium/medium-large at the end of nursery (3-month follow-up) and at the start of formal schooling (6-month follow-up), and then become small to medium at the end of the first school year.

Factor Analysis

Before the mediation model was run, we ran a confirmatory factor analysis (CFA) with maximum likelihood estimation to determine the factor structure of the executive function tasks. In line with previous research with this age range, and in keeping with the tasks we administered (measures of working memory and inhibitory control), we tested two competing models: a one-factor model of executive function and a two-factor model comprising two latent factors: working memory and inhibitory control. Both the CFA model and the mediation model were run in MPlus v8 (Muthén & Muthén, 1998–2017). To assess model fit we used a range of recommended fit indices: the chi-square statistic (as a global indication of model fit), the comparative fit index (CFI), the standardized root mean squared residual (SRMR), and the root mean square error of approximation (RMSEA). Benchmarks for a good model fit are as follows: CFI > .95, SRMR < .08, RMSEA < .06 (Hu & Bentler, 1999). As models were nested, the chi-square difference test was used to compare model fit. Where models do not significantly differ, the simpler model is preferred based on parsimony (Bollen, 1989). The one-factor model where the tasks loaded onto a single "executive function" factor fit the data well ($\chi^2 = 0.63$, $df = 2$, CFI = 1.0, SRMR = .013, RMSEA = .00). The two-factor model also fit the data well ($\chi^2 = 0.23$, $df = 1$, CFI = 1.0, SRMR = .007, RMSEA = .00) but did not result in a significant improvement in fit over the one-factor model ($p = .527$), so the one-factor model was retained for parsimony. In addition, the correlation between the factors in the two-factor model was high ($r = .82$), suggesting the two factors had little unique explanatory power. The executive function latent factor explained over half of the

Table 2
Mean, Standard Deviation, and Effect Size (Cohen's d*) of SES on Executive Functions, Mathematical Skills, Classroom Engagement, and Vocabulary at Baseline for All Children*

	Low-SES *M* (*SD*)	High-SES *M* (*SD*)	*d*
BWS	0.92 (1.08)	1.25 (1.31)	.28
Corsi	3.59 (1.71)	3.55 (1.97)	.02
Peg Tapping	4.86 (4.90)	7.62 (3.94)	.62
Stroop	6.97 (4.43)	8.04 (4.30)	.25
Maths	6.62 (2.34)	7.84 (3.18)	.44
CE	14.66 (2.48)	15.00 (2.69)	.13
Vocab	5.77 (2.30)	5.82 (2.06)	.02

Note. BWS = backwards word span; Stroop = black-white Stroop; CE = classroom engagement; vocab = receptive vocabulary; SES = socioeconomic status.

Table 1
Pearson's Correlations for All Measures at Baseline

	M (*SD*)	BWS	Corsi	Peg Tapping	Stroop	Maths	CE	Vocab
BWS	1.05 (1.18)							
Corsi	3.58 (1.81)	.15*						
Peg Tapping	5.91 (4.74)	.21**	.28***					
Stroop	7.38 (4.40)	.17*	.16*	.38***				
Maths	7.10 (2.75)	.33***	.44***	.41***	.35***			
CE	14.79 (2.56)	.11	.19*	.28***	.23**	.27***		
Vocab	5.79 (2.21)	.18*	.20**	.10	.10	.20**	.15*	

Note. BWS = backwards word span; Stroop = black-white Stroop; CE = classroom engagement; vocab = receptive vocabulary.
*$p < .05$. **$p < .01$. ***$p < .001$.

variability in the Peg Tapping task (R^2 = .55), a quarter of the variability in the Black–White Stroop task (R^2 = .26), and slightly less variability in working memory (R^2 = .10) and short-term memory (R^2 = .14). This pattern is consistent with the definition of executive function as one construct that contributes to performance on any individual task (Miyake et al., 2000), and with the one-factor structure of executive function previously reported in preschoolers (Wiebe et al., 2008, 2011).

Mediation Model

The mediation model was fit with SES as the predictor, the latent factor executive function as the mediator, and mathematical skills as the outcome variable. The first stage involved testing a model that included both direct and indirect effects; the second stage involved calculating the significance of the indirect effect. To do this, we used the bootstrapping procedure recommended by Preacher and Hayes (2004, 2008) because it has been shown to have higher power while maintaining reasonable control over the Type I error rate, more than other mediation procedures (such as the Sobel test: MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002). Ten thousand resamples of the data were used to estimate the indirect effect. A significant mediated effect is indicated by a point estimate of the product of coefficient that has bias-corrected 95% CIs in which the upper or lower bounds do not include zero. In the total effect model, SES had a significant, positive effect on mathematical skills (β = .22, p = .003). In the mediated model, SES had a significant, positive effect on executive functions (β = .29, p = .008), and executive functions had a significant positive effect on mathematical skills (β = .79, p < .001). When executive functions were controlled for in the indirect model, SES had no significant effect on mathematical skills (β = −.01, p = .934). The results of the bootstrapping procedure revealed the indirect effect was significant, as it did not have CIs that passed through zero (95% CI [0.31, 2.61]) showing that executive functions mediated the relation between SES and mathematical skills (see Figure 2). The model results remained the same when vocabulary was included as a covariate (indirect effect 95% CI [0.28, 2.73]).

The Effect of the Intervention

Age (t(173) = 0.12, p = .908), sex (χ^2(N = 175) = 3.58, p = .058), and SES (χ^2(N = 175) = 1.66, p = .684) did not significantly vary by group. There were no differences between groups in executive functions, mathematical skills, or vocabulary at baseline (ts = 0.13–1.65, ps = .10–.90). Of the 175 children allocated to condition, 74% (N = 135) completed all four intervention sessions, 21% (N = 36) completed three sessions, 4% (N = 7) completed two training sessions, and 1% completed one training session (N = 2). The number of sessions completed did not significantly differ between the training group (M = 3.63, SD = 0.68) and the active control group (M = 3.73, SD = 0.52), t(173) = 1.04, p = .301. Furthermore, participation in the training sessions did not vary by SES (t(85) = −1.56, p = .122). Table 3 reports descriptive data for each of the outcome measures by group at each time point. Table 4 presents these data broken down by SES.

Before testing for transfer to nontrained tasks, we explored whether children showed signs of improvement on the training tasks themselves, and whether any improvements differed as a function of SES. For this analysis, accuracy could not be examined as children were at different difficulty levels. Therefore, we examined whether children had improved and moved up a level by the final training session (*yes* or *no*), and whether this varied by SES. For the Six Boxes task, there was no significant difference in whether low-SES children improved (69%) compared to high-SES children (67%), χ^2(N = 63) = 0.6, p = .815. For the One-Back task, there was no significant difference in whether low-SES children improved (86%) compared to high-SES children (93%), χ^2(N = 63) = 0.74, p = .391. For the Flanker task, low-SES children (22%) were significantly less likely to improve compared to high-SES children (50%), χ^2(N = 63) = 5.20, p = .023. For the Go-No-Go task, there was no significant difference in whether low-SES children improved (97%) compared to high-SES children (96%), χ^2(N = 63) = 0.03, p = .856.

The critical test was whether the training intervention improved children's performance on different, nontrained measures. In the primary analyses, we ran analyses of covariance with group as the independent variable, baseline performance as the covariate, and the relevant test of executive functions or mathematic as the outcome variable. There were no significant effects of group on children's executive functions, mathematical skills, or classroom engagement at any of the posttraining time points. There was no effect of training on working memory at posttest (F(1, 168) = 0.29, p = .594, η^2_p = .002), 3 months (F(1, 167) = 0.35, p = .557, η^2_p = .002), 6 months (F(1, 147) = 0.83, p = .363, η^2_p = .0

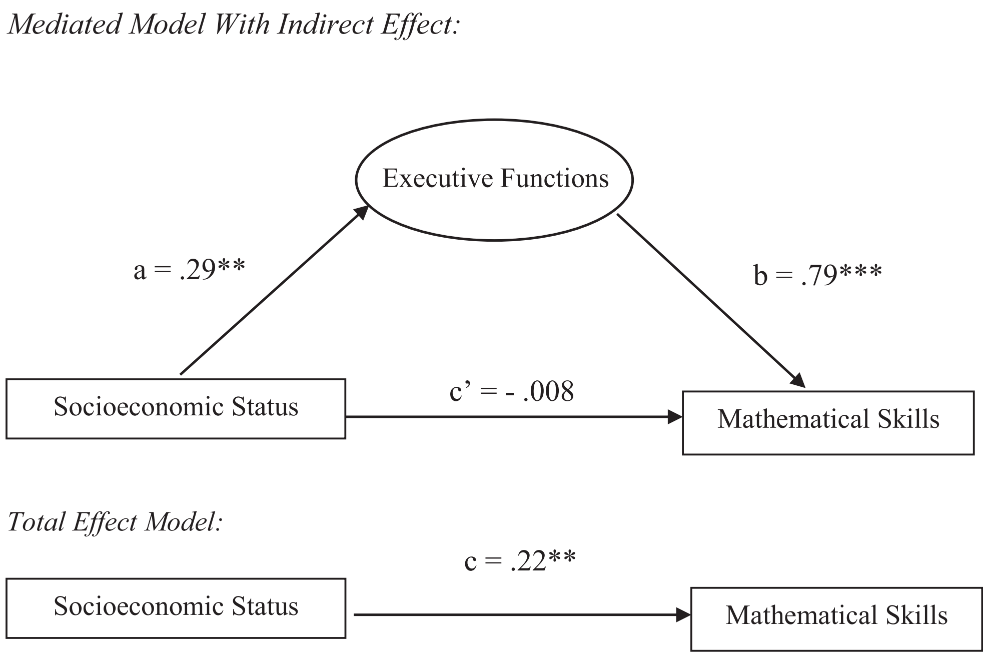

Figure 2. Mediation model showing the relation between socioeconomic status and mathematical skills as mediated by executive functions at baseline. Standardized beta weights are given.
$^{**}p < .01$. $^{***}p < .001$.

06) or 1 year ($F(1, 144) = 0.28$, $p = .598$, $\eta_p^2 = .002$). There was no effect on short-term memory at posttest ($F(1, 168) = 0.17$, $p = .683$, $\eta_p^2 = .001$), 3 months ($F(1, 168) = 0.19$, $p = .662$, $\eta_p^2 = .001$), 6 months ($F(1, 147) = 0.10$, $p = .749$, $\eta_p^2 = .001$), or 1 year ($F(1, 144) = 1.09$, $p = .298$, $\eta_p^2 = .01$). There was no effect on inhibitory control at posttest (Peg Tapping: $F(1, 166) = 1.44$, $p = .231$, $\eta_p^2 = .01$; Stroop: $F(1, 168) = 0.007$, $p = .935$, $\eta_p^2 < .001$), 3 months (Peg Tapping: $F(1, 166) = 1.22$, $p = .271$, $\eta_p^2 = .01$; Stroop: $F(1, 166) = 0.66$, $p = .419$), 6 months (Peg Tapping: $F(1, 146) = 2.55$, $p = .112$, $\eta_p^2 = .02$; Stroop: $F(1, 147) = 0.54$, $p = .464$, $\eta_p^2 = .004$), or 1 year (Peg Tapping: $F(1, 143) = 0.14$, $p = .706$, $\eta_p^2 = .001$; Stroop: $F(1, 144) = 0.13$, $p = .723$, $\eta_p^2 = .001$). There was no effect on mathematical reasoning at posttest ($F(1, 169) = 0.26$, $p = .612$, $\eta_p^2 = .002$), 3 months ($F(1, 168) = 2.38$, $p = .125$, $\eta_p^2 = .01$), 6 months ($F(1, 147) = 0.80$, $p = .374$, $\eta_p^2 = .005$), or 1 year ($F(1, 144) = 0.97$, $p = .328$, $\eta_p^2 = .01$). There was no effect on classroom engagement at 3 months ($F(1, 170) < 0.001$, $p = .994$, $\eta_p^2 < .001$), 6 months ($F(1, 145) = 1.62$, $p = .205$, $\eta_p^2 = .01$), or 1 year ($F(1, 144) = 0.08$, $p = .777$).

As planned secondary analyses, we added an SES × Group interaction to the model to examine whether training was more effective for high or low-SES children. There were no significant interactions between group and SES on inhibitory control, short-term memory, mathematical skills, or classroom engagement ($F_{MAX}(1, 168) = 2.71$, $p = .101$; $F_{MIN}(1, 166) = 0.008$, $p = .930$). There was a small but marginally significant interaction between group and SES for working memory at 1 year posttest, $F(1, 142) = 3.81$, $p = .053$ and .03. Bonferroni-adjusted pairwise comparisons showed that high-SES children in the training group had significantly higher working memory than low-SES children in the training group ($M_{diff} = 1.02$, $p = .006$ [0.30, 1.73]); that high-SES children in the training group had marginally higher working memory than high-SES children in the control group ($M_{diff} = 0.75$, $p = .061$ [−0.04, 1.53]); but that low-SES children in the training group and low-SES children in the control group did not significantly differ ($M_{diff} = -0.24$, $p = .447$ [−0.85, 0.38]. To examine this marginal interaction further, we ran a Bayesian analysis of covariance model in JASP v8 (https://jasp-stats.org/) with default priors allowing us to evaluate the strength of the evidence for the interaction. We compared the model with the main effects and interaction (SES × Group) against a null model with just working memory at baseline as a covariate. The evidence for the null was 3.6 times stronger than the evidence for the interaction model ($BF_{10} = 0.28$; see Table 5), suggesting that there was more evidence

Table 3
Means and Standard Deviations for Each Measure by Each Group and for the Baseline, Posttest, 3 Months, 6 Months, and 1 Year Posttest Assessments

	Executive function training group					Active control group				
	Baseline	Posttest	3 Months	6 Months	1 Year	Baseline	Posttest	3 Months	6 Months	1 Year
Working memory										
BWS	1.03 (1.14)	1.63 (1.30)	2.37 (1.57)	2.40 (1.55)	3.39 (1.61)	1.06 (1.23)	1.76 (1.45)	2.24 (1.69)	2.70 (1.59)	3.25 (1.46)
Corsi	3.69 (1.94)	3.92 (1.72)	4.11 (1.67)	4.41 (1.95)	5.64 (2.04)	3.47 (1.67)	3.91 (1.71)	4.13 (1.53)	4.45 (1.73)	5.23 (2.23)
Inhibitory control										
Peg Tapping	6.39 (4.71)	8.13 (4.22)	9.08 (3.47)	10.21 (2.83)	11.10 (1.43)	5.43 (4.75)	8.15 (4.32)	9.17 (3.65)	10.53 (2.29)	10.88 (1.78)
BW Stroop	7.93 (4.16)	9.46 (3.16)	9.12 (3.91)	10.23 (2.73)	10.63 (2.39)	6.84 (4.59)	9.07 (3.74)	9.36 (3.17)	9.62 (3.39)	10.67 (2.27)
Academic skills										
Maths	7.44 (2.68)	7.78 (3.37)	9.00 (3.50)	9.96 (3.50)	12.76 (3.18)	6.76 (2.80)	7.09 (3.06)	7.89 (2.98)	9.00 (3.46)	11.87 (3.27)
CE	14.92 (2.69)		15.29 (2.70)	14.74 (2.58)	15.06 (2.57)	14.67 (2.43)		15.10 (2.61)	15.16 (2.39)	15.15 (2.68)
Vocabulary	5.62 (2.24)					5.95 (2.17)				

Note. BWS = backwards word span; BW Stroop = black-white Stroop; CE = classroom engagement.

for there being no interaction between group and SES for working memory at 1 year posttest.

Discussion

Socioeconomic attainment gaps in mathematics start early and have the potential to perpetuate the cycle of inequality. We currently have a limited understanding of why SES attainment gaps arise. The aim of this study was to examine whether executive functions explain SES attainment gaps in early mathematical skills. To do this we examined relations between executive functions and mathematical skills in a socially diverse sample of preschoolers, and then tested this prediction causally by running a RCT to test whether executive function training would narrow the attainment gap up to 1 year later. We found that executive functions did explain the link between SES and mathematical skills, suggesting that one way to narrow early attainment gaps may be to focus on improving these domain-general skills. We also found that executive functions correlated with mathematics, suggesting executive functions play an important role in early mathematics. However, while children improved on the trained tasks, no training benefits transferred to different untrained measures of executive functions and mathematics. These results go beyond previous research to show not merely that SES is associated with preschoolers' mathematical skills, but that this link is mediated by executive functions. One practical implication of this finding would be that any intervention designed to address poor mathematics performance in low-SES contexts should focus on children with poor executive functions.

The first aim of the study was to better understand the role of SES in early cognitive development and mathematical skills. In this study, SES was not correlated with cognitive performance in general, but it was associated with specific tasks. SES differences were found only on tasks with high executive function demands, rather than for less typical "executive" tasks such as visuospatial memory (see also Farah et al., 2006). This is important, because it shows that SES is not associated with cognitive development in general, or children's ability to stay on task. This is perhaps because executive functions' protracted development means that the factors underpinning the association with SES exert their influence for a longer period of time (Hackman et al., 2010). SES also correlated with early mathematical skills, and

Table 4
Means and Standard Deviations at Each Posttest Assessment for Each Measure by Each Group and Split by SES

	Executive function training group								Active control group							
	Low-SES				High-SES				Low-SES				High-SES			
	Posttest	3 Months	6 Months	1 Year	Posttest	3 Months	6 Months	1 Year	Posttest	3 Months	6 Months	1 Year	Posttest	3 Months	6 Months	1 Year
WM																
BWS	1.46 (1.16)	2.04 (1.44)	2.20 (1.39)	3.00 (1.51)	1.91 (1.47)	2.91 (1.63)	2.93 (1.70)	4.04 (1.58)	1.58 (1.23)	1.94 (1.49)	2.31 (1.63)	3.20 (1.49)	2.03 (1.71)	2.69 (1.88)	3.34 (1.32)	3.34 (1.45)
Corsi	3.73 (1.61)	4.06 (1.56)	4.07 (1.81)	5.60 (1.92)	4.22 (1.85)	4.19 (1.84)	4.96 (2.06)	5.70 (2.25)	3.85 (1.71)	4.17 (1.68)	4.04 (1.77)	5.41 (2.37)	4.00 (1.77)	4.06 (1.31)	5.14 (1.43)	4.93 (1.99)
IC																
Peg Tapping	7.10 (4.62)	8.65 (3.46)	9.69 (3.32)	10.84 (1.65)	9.81 (2.78)	9.78 (3.42)	11.04 (1.50)	11.52 (0.80)	6.75 (4.67)	8.13 (4.20)	10.21 (2.68)	10.63 (2.02)	10.29 (2.54)	10.71 (1.79)	11.07 (1.28)	11.28 (1.25)
Stroop	8.79 (3.48)	8.58 (4.17)	10.04 (2.88)	10.36 (2.63)	10.56 (2.17)	10.00 (3.32)	10.54 (2.50)	11.07 (1.90)	8.17 (4.08)	9.12 (3.17)	9.25 (3.52)	10.39 (2.55)	10.40 (2.74)	9.71 (3.18)	10.24 (3.12)	11.10 (1.68)
Academic																
Maths	6.58 (2.61)	8.10 (3.36)	8.96 (2.98)	12.20 (3.06)	9.75 (3.58)	10.47 (3.24)	11.57 (3.72)	13.70 (3.21)	6.29 (2.53)	7.27 (3.06)	8.33 (2.85)	11.50 (3.35)	8.29 (3.42)	8.80 (2.64)	10.10 (4.12)	12.45 (3.11)
CE		15.56 (2.25)	14.44 (2.45)	14.79 (2.53)		14.84 (3.32)	15.22 (2.76)	15.52 (2.62)		15.15 (2.44)	14.96 (2.34)	15.16 (2.65)		15.03 (2.90)	15.48 (2.47)	15.12 (2.78)

Note. WM = working memory; IC = inhibitory control; BWS = backwards word span; BW Stroop = black-white Stroop; CE = classroom engagement; SES = socioeconomic status.

our research showed that executive functions may mediate the link between SES and mathematics.

The most important outstanding question is to better identify *why* SES is associated with executive functions. While the empirical evidence demonstrating links between SES and executive functions is becoming increasingly clear (see Lawson et al., 2018), theoretical accounts explaining this relation are still lacking. We set out three main ways we think SES may impact executive function development. Firstly, SES may be associated with executive functions due to differences in parental scaffolding and responsiveness. The fact that links between SES and executive functions are apparent early in development suggests that parenting may be a key mechanism through which social inequality influences development. Parenting behaviors vary by SES (Evans, 2004) and parental scaffolding and responsiveness specifically are associated with children's executive functions (Hughes & Ensor, 2009; Sarsour et al., 2011). Therefore, parenting behaviors may be a potential pathway through which SES influences executive function development, and subsequently, mathematical skills. Secondly, SES is associated with maternal and child language, which mediate the link between SES and executive functions (Daneri et al., 2018). It is important to note that executive functions mediate the association between SES and mathematical skills even *after* controlling for children's vocabulary—both here and in Dilworth-Bart (2012). However, it still remains likely that language skills contribute toward this relation, particularly as evidence suggests language may underpin executive functions by allowing children to effectively represent information related to goals (Gooch et al., 2016). Thirdly, growing up in a low-SES home—particularly at the extreme end of the SES spectrum, in poverty—may detrimentally impact executive functions when persistent stress is experienced (Amso & Lynn, 2017). Chronic levels of stress can lead to changes in the biological systems that respond to stress (Blair & Raver, 2012). This could in turn detrimentally affect executive functions, as the stress response system shares overlap with regions of the brain underpinning executive functions (Blair & Raver, 2012; McEwen et al., 2016).

These different mechanistic accounts of the SES-executive functions link are not mutually exclusive, and the relative contributions of each pathway may vary depending on the circumstances of the child and the extent of disadvantage. For example, the stress account likely cannot fully explain the link

Table 5
Bayes Factors for Group, SES, and the Interaction With Working Memory 1 year Later Controlling for Baseline Working Memory

Models	$P(M)$	$P(M\|data)$	BF_M	BF_{10}	Error %
Null model (incl. baseline working memory)	0.200	0.327	1.942	1.000	
Group	0.200	0.065	0.280	0.200	0.985
SES	0.200	0.441	3.154	1.349	16.715
Group + SES	0.200	0.077	0.332	0.234	2.145
Group + SES + Group × SES	0.200	0.090	0.397	0.276	2.228

Note. All models include working memory at baseline. SES = socioeconomic status.

between SES and executive functions across the SES gradient, as it is unlikely that all low-SES families experience stress. Moreover, associations between SES and executive functions are found along the full SES gradient (and not only in cases of extreme adversity). Given that executive functions play a crucial role in explaining attainment gaps, further work is now needed to tease apart these possible explanations for why SES may affect executive functions, and to elucidate under what circumstances these mechanisms play a role.

While the results suggest an important role for executive functions in explaining early attainment gaps, clearly, this study does not offer a full account of all the possible mediators of the relation between SES and mathematical skills. SES is likely to be associated with mathematical skills due a number of more or less direct pathways. This study suggests an important role for indirect effects via cognitive development. However, it is possible that more direct mediators play a role, such as the frequency of mathematical learning activities children engage in at home. Mathematical activities in the home correlate with SES and predict later mathematical skills (Melhuish et al., 2008; Skwarchuk, Sowinski, & LeFevre, 2014). Higher SES parents may have more resources to engage in home learning activities, and generally report more positive attitudes toward mathematics which may explain these SES differences (Elliott & Bachman, 2018). No studies have examined the role of *both* direct and indirect mediators in explaining the effects of SES on mathematical skills. A limitation of this study is that we were not able to collect contextual measures of parental stress or qualitative measures of parenting behavior. An important next step will be to examine both direct and indirect effects in large and diverse samples, and to collect these contextual measures so we can develop a comprehensive account of why SES attainment gaps arise.

The present results are informative for our understanding of how early mathematical skills are underpinned by domain-general processes. These results are particularly important as they focus on preschool mathematical skills—in contrast to most previous research, which has focused on school-age children (Bull, Espy, & Wiebe, 2008; Clark, Pritchard, & Woodward, 2010; Cragg & Gilmore, 2014). In this study, visuospatial memory and inhibitory control showed particularly strong correlations with preschoolers' mathematical skills. Visuospatial memory may help children to construct, process and maintain visual representations including both symbolic numbers and non-symbolic arrays, as well as number lines (Kyttälä, Aunio, Lehto, Van Luit, & Hautamäki, 2003). Inhibitory control has been studied less in young children, but research has shown that it predicts mathematical skills in young children who have mathematical difficulties (Geary, Hoard, & Bailey, 2012; Passolunghi & Pazzaglia, 2005). Inhibitory control may help children to suppress automatic but incorrect answers or help to inhibit attention to salient but irrelevant distractors. The results support theoretical models of mathematical development that include executive functions as a key component or pathway (Geary, 2004; LeFevre et al., 2010). Future research may wish to explore further the role of cognitive flexibility, another key executive function, in mathematical skills. We would predict that cognitive flexibility may support more advanced mathematical skills, when children need to switch between multiple operations, such as during arithmetic.

The second aim of this study was to determine if an executive function training intervention can improve both executive functions and mathematical skills in a diverse sample of preschoolers. In doing so, this allowed us to causally test our specific hypothesis that executive functions underpin mathematical skills and mediate social attainment gaps. Very little work has causally examined this hypothesis, with few training studies examining whether executive function training is effective in young children from socially diverse backgrounds.

We hypothesized that the intervention would improve working memory and aimed to explore whether this would lead to improvements in mathematical skills. While children's performance improved over training, against our hypothesis, we found that the intervention was not effective in improving nontrained executive functions or mathematical skills. We do not believe these results mean that executive functions are not causally related to mathematical skills. Instead, the lack of transfer to executive functions suggests that any far transfer to mathematical skills would not be expected. The fact that we found no far transfer to mathematical skills or to classroom engagement adds to a growing literature demonstrating that cognitive training targeting executive functions does not transfer to children's academic skills (Ang, Lee, Cheam, Poon, & Koh, 2015; Dunning, Holmes, & Gathercole, 2013). However, the lack of near transfer to untrained measures of working memory was unexpected, particularly because in a smaller scale study with mid-SES children this training program improved working memory. Importantly, this study used the same tasks and procedures as this previous study, with the only difference being the larger, more diverse and slightly younger sample. We further hypothesized that low-SES children would show the most benefit from the training. Studies have supported the idea of so-called "compensatory effects" where bigger intervention effects are found for participants who begin with a low initial starting point. In particular, interventions have reported greater success in children from low-SES backgrounds in terms of executive functions (Blair & Raver, 2014), mathematical skills (Ramani & Siegler, 2008), and language (McGillion, Pine, Herbert, & Matthews, 2017). However, we found that SES was not related to transfer. One possible explanation that may account for why the intervention did not lead to improvements *and* why there was no interaction with SES is that the training program did not improve the capacity or efficiency of executive functions; but that the children, particularly high-SES children, were able to improve over training as they were able to devise some task-specific strategies on the tasks (see Dunning & Holmes, 2014, for a similar suggestion in adults). The lack of transfer to very different tasks may be because these strategies were not useful on tasks with different formats and instructions. A broader point that arises from these findings, particularly the failure to replicate the effect on working memory, is the importance of replicating positive findings from smaller samples in large, well-powered studies.

A further possible explanation of our results is that brief computerized cognitive training is more generally not an effective way to promote executive functions and mathematical skills. It is possible that particularly for preschoolers, for whom executive functions are not yet fully developed, brief computerized interventions that involve children completing specific tasks is not enough to improve executive function capacity. Interventions may need to be more sustained, or more importantly, they may need to be embedded within the learning tasks we wish to nurture. This is particularly pertinent to early mathematical skills where children may need practice *while learning* to apply executive functions strategies, and furthermore, may need instruction from others who can scaffold their learning and demonstrate learning principles. We discuss this idea in more detail further below.

Related to this point, a potential limitation of the present intervention is that it was brief, taking place over only four sessions. It is possible that a more extensive or intensive intervention would have led to transfer effects. We designed the training program to be brief for three reasons. Firstly, prior research has shown that brief cognitive training interventions are as effective as longer ones in young children (e.g., Rueda et al., 2005; Wass et al., 2011). Secondly, attendance in preschool is known to be important in narrowing attainment gaps (Sylva et al., 2011). Therefore, while one might speculate that more intensive training programs could be more effective overall, they arguably may not help to close attainment gaps, as participating children, of necessity, must spend extended periods of time away from their classroom. Thirdly, several meta-analyses on executive function training have found that the duration of training is unrelated to the degree of transfer in both children and adults (e.g., Kassai et al., 2019; Melby-Lervåg et al., 2016; Sala & Gobet, 2017). This is interesting, because if training is truly improving the underlying construct, we would expect the duration of training and the magnitude of transfer to be positively correlated. One hypothesis is that a minimum number of sessions is needed in order for training studies to show an effect—after which point there are diminishing returns. Another hypothesis is that training duration is unrelated to transfer because training may improve task-specific skills or strategies (as opposed to the underlying construct); these can be picked up quickly, and once learned, remain stable.

Another limitation is that the intervention only focused on a single domain and did not intervene more broadly on factors such as classroom quality or family functioning. In order to narrow the social attainment gap, it is likely that sustained and broad interventions are needed that address inequalities at all levels, including structural barriers, the family and the broader learning environment. We aimed to focus on executive functions primarily because interventions focusing on single domains can better identify causal mechanisms (Wass, 2015), and the aim of our study was to causally test our prediction that executive functions are a key factor that may explain SES attainment gaps. However, interventions that take a more holistic approach and in particular, ones that integrate more intensive interventions into classrooms have found positive and lasting effects on executive functions (e.g., Raver et al., 2011). Also, small but significant effects following classroom interventions have been found on broader academic skills and social skills (Bierman et al., 2008), as well as with self-regulation (Schmitt, McClelland, Tominey, & Acock, 2015). Therefore, these approaches may prove to be a more effective direction for future intervention work. One strength of these approaches is that they do not require children to be taken away from the classroom, since they embed the intervention within the learning activities themselves.

The present results suggest that cognitive training might not be an effective way to narrow SES attainment gaps, and that it may not be possible to improve the capacity or efficiency of executive function through training. Instead, it may be more fruitful for cognitive interventions to focus on skills such as metacognition and strategy use, and for broader holistic interventions to tackle social attainment gaps via family-based and classroom-based approaches. Indeed, these approaches may be more helpful for narrowing attainment gaps in *early* mathematical skills. It is important to remember that interaction with others is often at the heart of children's learning (Bodrova & Leong, 2007; Karpov, 2005; Vygotsky, 1978). Preschoolers have both limited executive functions and are just beginning to learn foundational mathematics. Therefore, interventions that build in interaction as part of the intervention—as opposed to completing cognitive tasks in isolation—are likely to be more fruitful for young children who are learning to apply executive functions within their learning. In addition, as children are learning new skills, it may be that strategy and metacognition are more helpful while executive functions are still developing as they provide "shortcuts" that can compensate for rudimentary skills. Strategies and metacognition may provide a way to more efficiently apply executive functions given evidence suggesting improving capacity via cognitive training is limited.

Given the vital role executive functions clearly play in mathematical skills, we propose two alternative approaches to early interventions that could be adopted in future research that take this developmental perspective. Firstly, interventions could examine whether embedding executive function activities into the curriculum helps children's mathematical development (e.g., Tominey & McClelland, 2011). A promising example of this is the Tools of the Mind curriculum that takes a Vygotskian approach and embeds executive function activities into group school learning activities guided by a teacher (Diamond, Barnett, Thomas, & Munro, 2007). Studies have found that this program leads to improvements in executive functions and mathematics, particularly for children from low-income backgrounds (Blair & Raver, 2014). This approach is likely to be successful for young children as children are learning to use executive functions while they are engaging in the learning activities themselves and while also giving them the opportunity to observe and learn from others. The second contrasting approach would be to aim to reduce incidental executive function demands on learning tasks, thus helping to scaffold children who might be struggling (see also Gathercole & Alloway, 2008). Given that executive functions are not yet fully developed in preschoolers, this could involve easing the load on working memory within mathematics activities by deliberately reducing the number of steps that need to be performed in sequence, breaking down tasks into smaller components, or using visual aids and strategies to aid the retention and retrieval of information. To reduce inhibitory control demands, children could be encouraged to slow down when they are learning new material, to avoid them unreflectively following strategies or answers that are automatic but incorrect. Advantages of these approaches are that they would not involve taking children out of class, or purchasing expensive equipment, and could be easily implemented by educators. It will be important for future studies to continue to test these approaches in diverse samples, and to see whether they are more helpful for children who have poor executive functions to begin with.

In summary, this study shows that executive functions play a crucial role in early mathematical skills, and that they mediate early SES attainment gaps. However, training on a set of executive function tasks, while effective in promoting learning on those tasks, did not improve performance on different executive function tasks or on a measure of mathematics. These findings are particularly noteworthy as they come from a large and socially diverse sample. Furthermore, they demonstrate that SES has a disproportionate effect on executive functions. This study lays an important foundation for further exploration of the role of SES in executive function development, and for designing interventions to narrow attainment gaps that consider executive functions. Future studies should explore *why* SES is associated with executive functions, so that more effective pedagogical tools can be created to reduce social inequalities in early mathematical development.

References

Adler, N. E., & Snibbe, A. C. (2003). The role of psychosocial processes in explaining the gradient between socioeconomic status and health. *Current Directions in Psychological Science*, *12*, 119–123. https://doi.org/10.1111/1467-8721.01245

Alloway, T. P., & Passolunghi, M. C. (2011). The relationship between working memory, IQ, and mathematical skills in children. *Learning and Individual Differences*, *21*, 133–137. https://doi.org/10.1016/j.lindif.2010.09.013

Amso, D., & Lynn, A. (2017). Distinctive mechanisms of adversity and socioeconomic inequality in child development: A review and recommendations for evidence-based policy. *Policy Insights from the Behavioral and Brain Sciences*, *4*, 139–146. https://doi.org/10.1177/2372732217721933

Ang, S. Y., Lee, K., Cheam, F., Poon, K., & Koh, J. (2015). Updating and working memory training: Immediate improvement, long-term maintenance, and generalisability to non-trained tasks. *Journal of Applied Research in Memory and Cognition*, *4*, 121–128. https://doi.org/10.1016/j.jarmac.2015.03.001

Aunola, K., Leskinen, E., Lerkkanen, M. L., & Nurmi, J. E. (2004). Developmental dynamics of math performance from pre-school to Grade 2. *Journal of Educational Psychology*, *96*, 713. https://doi.org/10.1037/0022-0663.96.4.699

Ballieux, H., Wass, S. V., Tomalski, P., Kushnerenko, E., Karmiloff-Smith, A., Johnson, M., & Moore, D. G. (2016). Applying gaze-contingent training within community settings to infants from diverse SES backgrounds. *Journal of Applied Developmental Psychology*, *43*, 8–17. https://doi.org/10.1016/j.appdev.2015.12.005

Berkman, N. D., Sheridan, S. L., Donahue, K. E., Halpern, D. J., & Crotty, K. (2011). Low health literacy and health outcomes: An updated systematic review. *Annals of Internal Medicine*, *155*, 97–107. https://doi.org/10.7326/0003-4819-155-2-201107190-00005

Bierman, K. L., Domitrovich, C. E., Nix, R. L., Gest, S. D., Welsh, J. A., & Greenberg, M. T. (2008). Promoting academic and social-emotional school readiness: The Head Start REDI program. *Child Development*, *179*, 1802–1817. https://doi.org/10.1111/j.1467-8624.2008.01227.x

Blair, C., & Raver, C. C. (2012). Child development in the context of adversity. *American Psychologist*, *67*, 309–318. https://doi.org/10.1037/a0027493

Blair, C., & Raver, C. C. (2014). Closing the achievement gap through modification of neurocognitive and neuroendocrine function: Results from a cluster randomized controlled trial of an innovative approach to the education of children in kindergarten. *PLoS ONE*, *9*, e112393. https://doi.org/10.1371/journal.pone.0112393

Blair, C., & Raver, C. C. (2015). School readiness and self-regulation: A developmental psychobiological approach. *Annual Review of Psychology*, *66*, 711–731. https://doi.org/10.1146/annurev-psych-010814-015221

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development*, *78*, 647–663.

Blair, C., Ursache, A., Greenberg, M., Vernon-Feagans, L.; The Family Life Project Investigators. (2015). Multiple aspects of self-regulation uniquely predict mathematics but not letter-word knowledge in the early elementary grades. *Developmental Psychology*, *51*, 459–472. https://doi.org/10.1037/a0038813

Blakey, E., & Carroll, D. J. (2015). A short executive function training program improves preschoolers' working memory. *Frontiers in Psychology*, *6*, 1827. https://doi.org/10.3389/fpsyg.2015.01827

Bodrova, E., & Leong, D. J. (2007). *Tools of the mind: The Vygotskian approach to early childhood education* (2nd ed.). New York, NY: Merrill/Prentice Hall.

Bollen, K. A. (1989). *Structural equation models with latent variables*. New York, NY: Wiley.

Bradley, R. H., & Corwyn, R. F. (2002). Socioeconomic status and child development. *Annual Review of Psychology*, *53*, 371–399. https://doi.org/10.1146/annurev.psych.53.100901.135233

Bull, R., Espy, K. A., & Wiebe, S. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology*, *33*, 205–228. https://doi.org/10.1080/87565640801982312

Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology*, *19*, 273–293. https://doi.org/10.1207/S15326942DN1903_3

Chevalier, N., Sheffield, T. D., Nelson, J. M., Clark, C. A., Wiebe, S. A., & Espy, K. A. (2012). Underpinnings of the costs of flexibility in preschool children: The roles of inhibition and working memory. *Developmental*

Neuropsychology, *37*, 99–118. https://doi.org/10.1080/87565641.2011.632458

Clark, C. A. C., Pritchard, V. E., & Woodward, L. J. (2010). Preschool executive functioning abilities predict early mathematics achievement. *Developmental Psychology*, *46*, 1176–1191. https://doi.org/10.1037/a0019672

Corsi, P. M. (1972). Human memory and the medial temporal region of the brain. Unpublished PhD dissertation, McGill University, Montreal, QC.

Cragg, L., & Gilmore, C. (2014). Skills underlying mathematics: The role of executive function in the development of mathematics proficiency. *Trends in Neuroscience and Education*, *3*(2), 63–68. https://doi.org/10.1016/j.tine.2013.12.001

Daneri, M. P., Blair, C., Kuhn, L. J.; FLP Key Investigators. (2018). Maternal language and child vocabulary mediate relations between socioeconomic status and executive function during early childhood. *Child Development*, *90*, 2001–2018. https://doi.org/10.1111/cdev.13065

Davis, H. L., & Pratt, C. (1996). The development of children's theory of mind: The working memory explanation. *Australian Journal of Psychology*, *47*, 25–31. https://doi.org/10.1080/00049539508258765

Devine, R. T., Bignardi, G., & Hughes, C. (2016). Executive function mediates the relations between parental behaviors and children's early academic ability. *Frontiers in Psychology*, *7*, 1902. https://doi.org/10.3389/fpsyg.2016.01902

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science*, *318*, 1387–1388. https://doi.org/10.1126/science.1151148

Diamond, A., Prevor, M., Callender, G., & Druin, D. P. (1997). Prefrontal cortex cognitive deficits in children treated early and continuously for PKU. *Monographs of the Society for Research in Child Development*, *62* (Serial No. 252), 1–7. https://doi.org/10.2307/1166208

Diamond, A., & Taylor, C. (1996). Development of an aspect of executive control: Development of the abilities to remember what I said and to "do as I say, not as I do." *Developmental Psychobiology*, *29*, 315–334. https://doi.org/10.1002/(SICI)1098-2302(199605)29:4<315:AID-DEV2>3.0.CO;2-T

Dilworth-Bart, J. E. (2012). Does executive function mediate SES and home quality associations with academic readiness? *Early Childhood Research Quarterly*, *27*, 416–425. https://doi.org/10.1016/j.ecresq.2012.02.002

Duncan, G. J., Claessens, A., Huston, A. C., Pagani, L. S., Engel, M., Sexton, H., . . . Japel, C. (2007). School readiness and later achievement. *Developmental Psychology*, *43*, 1428–1446. https://doi.org/10.1037/0012-1649.43.6.1428

Duncan, G. J., & Magnuson, K. (2012). Socioeconomic status and cognitive functioning: Moving from correlation to causation. *Wiley Interdisciplinary Reviews: Cognitive Science*, *3*, 377–386. https://doi.org/10.1002/wcs.1176

Dunning, D. L., & Holmes, J. (2014). Does working memory training promote the use of strategies on untrained working memory tasks? *Memory & Cognition*, *42*, 854–862. https://doi.org/10.3758/s13421-014-0410-5

Dunning, D. L., Holmes, J., & Gathercole, S. E. (2013). Does working memory training lead to generalized improvements in children with low working memory? A randomized controlled trial. *Developmental Science*, *16*, 915–925. https://doi.org/10.1111/desc.12068

Elliott, L., & Bachman, H. J. (2018). How do parents foster young children's math skills? *Child Development Perspectives*, *12*, 16–21. https://doi.org/10.1111/cdep.12249

English Indices of Deprivation. (2015, September 30). Ministry of Housing, Communities and Local Government. Retrieved from https://www.gov.uk/government/statistics/english-indices-of-deprivation-2015

Evans, G. W. (2004). The environment of childhood poverty. *American Psychologist*, *59*, 77–92. https://doi.org/10.1037/0003-066X.59.2.77

Farah, M. J., Shera, D. M., Savage, J. H., Betancourt, L., Giannetta, J. M., Brodsky, N. L., . . . Hurt, H. (2006). Childhood poverty: Specific associations with neurocognitive development. *Brain Research*, *1110*, 166–174. https://doi.org/10.1016/j.brainres.2006.06.072

Fay-Stammbach, T., Hawes, D. J., & Meredith, P. (2014). Parenting influences on executive function in early childhood: A review. *Child Development Perspectives*, *8*, 258–264. https://doi.org/10.1111/cdep.12095

Fitzpatrick, C., McKinnon, R. D., Blair, C. B., & Willoughby, M. T. (2014). Do preschool executive function skills explain the school readiness gap between advantaged and disadvantaged children? *Learning and Instruction*, *30*, 25–31. https://doi.org/10.1016/j.learninstruc.2013.11.003

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin*, *134*, 31–60. https://doi.org/10.1037/0033-2909.134.1.31

Gathercole, S. E., & Alloway, T. P. (2008). *Working memory and learning: A practical guide for teachers*. London, UK: Sage.

Gathercole, S. E., & Pickering, S. J. (2000). Working memory deficits in children with low achievements in the national curriculum at 7 years of age. *British Journal of Educational Psychology*, *70*, 177–194. https://doi.org/10.1348/000709900158047

Geary, C. (2004). Mathematics and learning disabilities. *Journal of Learning Disabilities*, *37*, 4–15. https://doi.org/10.1177/00222194040370010201

Geary, D. C., Hoard, M. K., & Bailey, D. H. (2012). Fact retrieval deficits in low achieving children and children with mathematical learning disability. *Journal of Learning Disabilities*, *45*, 291–307. https://doi.org/10.1177/0022219410392046

Gerstadt, C. L., Hong, Y. J., & Diamond, A. (1994). The relationship between cognition and action: Performance of children 3–7 years old on a stroop-like day–night test. *Cognition*, *53*, 129–153. https://doi.org/10.1016/0010-0277(94)90068-x

Goldin, A. P., Hermida, M. J., Shalom, D. E., Elias Costa, M., Lopez-Rosenfeld, M., Segretin, M. S, . . . Sigman, M. (2014). Far transfer to language and math of a short software-based gaming intervention. *Proceedings of the National Academy of Sciences of the United States of America*, *111*, 6448. https://doi.org/10.1073/pnas.1320217111

Gooch, D., Thompson, P., Nash, H. M., Snowling, M. J., & Hulme, C. (2016). The development of executive function and language skills in the early school years. *Journal of Child Psychology and Psychiatry*, *57*, 180–187. https://doi.org/10.1111/jcpp.12458

Hackman, D. A., & Farah, M. J. (2009). Socioeconomic status and the developing brain. *Trends in Cognitive Sciences*, *13*, 65–73. https://doi.org/10.1016/j.tics.2008.11.003

Hackman, D. A., Farah, M. J., & Meaney, M. J. (2010). Socioeconomic status and the brain: Mechanistic insights from human and animal research. *Nature Reviews Neuroscience*, *11*, 651–659. https://doi.org/10.1038/nrn2897

Heckman, J. J. (2006). Skill formation and the economics of investing in disadvantaged children. *Science*, *312*, 1900–1902. https://doi.org/10.1126/science.1128898

Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling*, *6*, 1–55. https://doi.org/10.1080/10705519909540118

Hughes, C., & Ensor, R. (2009). How do families help or hinder the emergence of early executive function. *New directions for Child and Adolescent Development*, *123*, 35–50. https://doi.org/10.1002/cd.234

Jones, J. S., Milton, F., Mostazir, M., & Adlam, A.-L. R. (2019). The academic outcomes of working memory and metacognitive strategy training in children: A double-blind randomised controlled trial. *Developmental Science*, e12870. https://doi.org/10.1111/desc.12870

Jordan, N. C., & Levine, S. C. (2009). Socioeconomic variation, number competence, and mathematics learning difficulties in young children. *Developmental Disabilities Research Reviews*, *15*, 60–68. https://doi.org/10.1002/ddrr.46

Karalunas, S. L., Bierman, K. L., & Huang-Pollock, C. L. (2016). Test–retest reliability and measurement invariance of executive function tasks in young children with and without ADHD. *Journal of Attention Disorders*, 1–14. https://doi.org/10.1177/1087054715627488

Karbach, J., & Verhaeghen, P. (2014). Making working memory work: A meta-analysis of executive control and working memory training in younger and older adults. *Psychological Science*, *25*, 2027–2037. https://doi.org/10.1177/0956797614548725

Karmiloff-Smith, A. (1998). Development itself is the key to understanding developmental disorders. *Trends in Cognitive Sciences*, *2*, 389–398. https://doi.org/10.1016/S1364-6613(98)01230-3

Karpov, Y. V. (2005). *The neo-vygotskian approach to child development*. Cambridge, UK: Cambridge University Press.

Kassai, R., Futo, J., Demetrovics, Z., & Takacs, Z. K. (2019). A meta-analysis of the experimental evidence on the near- and far-transfer effects among children's executive function skills. *Psychology Bulletin*, *2*, 165–188. https://doi.org/10.1037/bul0000180

Kline, R. B. (2011). *Principles and practice of structural equation modeling* (3rd ed.). New York, NY: Guilford.

Kyttälä, M., Aunio, P., Lehto, J. E., Van Luit, J., & Hautamäki, J. (2003). Visuospatial working memory and early numeracy. *Educational and Child Psychology*, *20*, 65–76.

Lagattuta, K. H., Sayfan, L., & Monsour, M. (2011). A new measure for assessing executive function across a wide age range: Children and adults find happy-sad more difficult than day-night. *Developmental Science*, *14*, 481–489. https://doi.org/10.1111/j.1467-7687.2010.00994.x

Lawson, G. M., & Farah, M. J. (2017). Executive function as a mediator between SES and academic achievement throughout childhood. *International Journal of Behavioral Development*, *41*, 94–104. https://doi.org/10.1177/0165025415603489

Lawson, G. M., Hook, C. J., & Farah, M. J. (2018). A meta-analysis of the relationship between socioeconomic status and executive function performance among children. *Developmental Science*, *21*, e12529. https://doi.org/10.1111/desc.12529

LeFevre, J., Fast, L., Smith-Chant, B., Skwarchuk, S., Bisanz, J., Kamawar, D., & Penner-Wilger, M. (2010). Pathways to mathematics: Longitudinal predictors of performance. *Child Development*, *81*, 1753–1767. https://doi.org/10.1111/j.1467-8624.2010.01508.x

Leventhal, T., & Brooks-Gunn, J. (2000). The neighborhoods they live in: The effect of neighbourhood residence on child and adolescent outcomes. *Psychological Bulletin*, *126*, 309–337. https://doi.org/10.1037//0033-2909.126.2.309

MacKinnon, D. P., Lockwood, C. M., Hoffman, J. M., West, S. G., & Sheets, V. (2002). A comparison of methods to test mediation and other intervening variable effects. *Psychological Methods*, *7*, 83–104. https://doi.org/10.1037/1082-989X.7.1.83

McClelland, M. M., & Cameron, C. E. (2012). Self-regulation in early childhood: Improving conceptual clarity and developing ecologically valid measures. *Child Development Perspectives*, *6*, 136–142. https://doi.org/10.1111/j.1750-8606.2011.00191.x

McEwen, B. S., Nasca, C., & Gray, J. D. (2016). Stress effects on neuronal structure: Hippocampus, amygdala, and prefrontal cortex. *Neuropsychopharmacology*, *41*, 3–23. https://doi.org/10.1038/npp.2015.171

McGillion, M., Pine, J. M., Herbert, J. S., & Matthews, D. (2017). A randomised controlled trial to test the effect of promoting caregiver contingent talk on language development in infants from diverse socioeconomic status backgrounds. *Journal of Child Psychology and Psychiatry*, *58*, 1122–1131. https://doi.org/10.1111/jcpp.12725

Melby- Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology*, *49*, 270–286. https://doi.org/10.1037/a0028228

Melby-Lervåg, M., Redick, T. S., & Hulme, C. (2016). Working memory training does not improve performance on measures of intelligence or other measures of "far transfer:" Evidence from a meta-analytic review. *Perspectives on Psychological Science*, *11*, 512–534. https://doi.org/10.1177/1745691616635612

Melhuish, E. C., Phan, M. B., Sylva, K., Sammons, P., Siraj-Blatchford, I., & Taggart, B. (2008). Effects of home learning environment and preschool center experience upon literacy and numeracy development in early primary school. *Journal of Social Issues*, *64*, 95–114. https://doi.org/10.1111/j.1540-4560.2008.00550.x

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*, 49–100. https://doi.org/10.1006/cogp.1999.0734

Morgan, P. L., Farkas, G., & Wu, Q. (2009). Five-year growth trajectories of kindergarten children with learning difficulties in mathematics. *Journal of Learning Disabilities*, *42*, 306–321. https://doi.org/10.1177%2F0022219408331037

Muthén, L. K., & Muthén, B. O. (1998–2017). *Mplus user's guide*. Los Angeles, CA: Author.

Müller, U., Kerns, K. A., & Konkin, K. (2012). Test-retest reliability and practice effects of executive function tasks in preschool children. *The Clinical Neurologist*, *26*, 271–287. https://doi.org/10.1080/13854046.2011.645558

Nesbitt, K. T., Baker-Ward, L., & Willoughby, M. T. (2013). Executive function mediates socio-economic and racial differences in early academic achievement. *Early Childhood Research Quarterly*, *28*, 774–783. https://doi.org/10.1016/j.ecresq.2013.07.005

Noble, K. G., McCandliss, B. D., & Farah, M. J. (2007). Socioeconomic gradients predict individual differences in neurocognitive abilities. *Developmental Science*, *10*, 464–480. https://doi.org/10.1111/j.1467-7687.2007.00600.x.

Pagani, L. S., Fitzpatrick, C., Barnett, T. A., & Dubow, E. (2010). Prospective associations between early childhood television exposure and academic, psychosocial, and physical well-being by middle childhood. *Archives of Pediatrics Adolescent Medicine*, *164*, 425–431. https://doi.org/10.1001/archpediatrics.2010.50

Passolunghi, M. C., & Pazzaglia, F. (2005). A comparison of updating processes in children good or poor in arithmetic word problem-solving. *Learning and Individual Differences*, *15*, 257–269. https://doi.org/10.1016/j.lindif.2005.03.001

Preacher, K. J., & Hayes, A. F. (2004). SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behavior Research Methods, Instruments, and Computers*, *36*, 717–731. https://doi.org/10.3758/BF03206553

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods*, *40*, 879–891. https://doi.org/10.3758/BRM.40.3.879

Ragubar, K. P., Barnes, M. A., & Hecht, S. A. (2010). Working memory and mathematics: A review of developmental, individual difference, and cognitive approaches. *Learning and Individual Differences*, *20*, 110–122. https://doi.org/10.1016/j.lindif.2009.10.005

Ramani, G. B., & Siegler, R. (2008). Promoting broad and stable improvements in low-income children's numerical knowledge through playing number board games. *Child Development*, *79*, 375–394. https://doi.org/10.1111/j.1467-8624.2007.01131.x

Ramey, C. T., & Ramey, S. L. (1998). Early intervention and early experience. *American Psychologist*, *53*, 109–120. https://doi.org/10.1037/0003-066X.53.2.109

Rathbun, A., & West, J. (2004). *From kindergarten through third grade: Children's beginning school experiences (NCES 2004–007)*. U.S. Department of Education, National Center for Education Statistics. Washington, DC: Government Printing Office.

Raver, C. C., Jones, S. M., Li-Grining, C. P., Zhai, F., Bub, K., & Pressler, E. (2011). CSRP's impact on low-income preschoolers' preacademic skills: Self-regulation as a mediating mechanism. *Child Development*, *82*, 362–378. https://doi.org/10.1111/j.1467-8624.2010.01561.x

Ritchie, S. J., & Bates, T. C. (2013). Enduring links from childhood mathematics and reading achievement to adult socioeconomic status. *Psychological Science*, *24*, 1301–1308. https://doi.org/10.1177/0956797612466268

Rivera-Batiz, F. L. (1992). Quantitative literacy and the likelihood of employment among young adults in the United States. *Journal of Human Resources*, *27*, 313–328. https://doi.org/10.2307/145737

Rueda, M. R., Posner, M. I., & Rothbart, M. K. (2005). The development of executive attention: Contributions to the emergence of self-regulation. *Developmental Neuropsychology*, *28*, 573–594. https://doi.org/10.1207/s15326942dn2802_2

Sala, G., & Gobet, F. (2017). Working memory training in typically developing children: A metaanalysis of the available evidence. *Developmental Psychology*, *53*, 671–685. https://doi.org/10.1037/dev0000265

Sarsour, K., Sheridan, M., Jutte, D., Nuru-Jeter, A., Hinshaw, S., & Boyce, W. T. (2011). Family socioeconomic status and child executive functions: The roles of language, home environment, and single parenthood. *Journal of the International Neuropsychological Society*, *17*, 120–132. https://doi.org/10.1017/S1355617710001335

Schmitt, S. A., McClelland, M. M., Tominey, S. L., & Acock, A. C. (2015). Strengthening school readiness for Head Start children: Evaluation of a self-regulation intervention. *Early Childhood Research Quarterly*, *30*, 20–31. https://doi.org/10.1016/j.ecresq.2014.08.001

Schwaighofer, M., Fischer, F., & Buhner, M. (2015). Does working memory training transfer? A meta-analysis including training conditions as moderators. *Educational Psychologist*, *50*, 138–166. https://doi.org/10.1080/00461520.2015.1036274

Sektnan, S., McClelland, M. M., Acock, A., & Morrison, F. J. (2010). Relations between early family risk, children's behavioral regulation, and academic achievement. *Early Childhood Research Quarterly*, *25*, 464–479. https://doi.org/10.1016/j.ecresq.2010.02.005

Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Is working memory training effective? *Psychological Bulletin*, *138*, 628–654. https://doi.org/10.1037/a0027473

Simpson, A., & Riggs, K. J. (2006). Conditions under which children experience inhibitory difficulty with a "button-press" go/no-go task. *Journal of Experimental Child Psychology*, *94*, 18–26. https://doi.org/10.1016/j.jecp.2005.10.003

Skwarchuk, S., Sowinski, C., & LeFevre, J. (2014). Formal and informal home learning activities in relation to children's early numeracy and literacy skills: The development of a home numeracy model. *Journal of Experimental Child Psychology*, *121*, 63–84. https://doi.org/10.1016/j.jecp.2013.11.006

Starkey, P., & Klein, A. (2008). *Sociocultural influences on young children's mathematical knowledge. Contemporary perspectives on mathematics in early childhood education*. Charlotte, NC: Information Age.

Sylva, K., Melhuish, E., Sammons, P., Siraj-Blatchford, I., & Taggart, B. (2011). Pre-school quality and educational outcomes at age 11: Low quality has little benefit. *Journal of Early Childhood Research*, *9*, 109–124. https://doi.org/10.1177/1476718X10387900

Thorell, L. B., Lindqvist, S., Bergman, N., Bohlin, G., & Klingberg, T. (2008). Training and transfer effects of executive functions in preschool children. *Developmental Science*, *12*, 106–113. https://doi.org/10.1111/j.1467-7687.2008.00745.x

Titz, C., & Karbach, J. (2014). Working memory and executive functions: Effects of training on academic achievement. *Psychological Research Psychologische Forschung*, *78*, 852–868. https://doi.org/10.1007/s00426-013-0537-1

Tominey, S. L., & McClelland, M. M. (2011). Red light, purple light: Findings from a randomized trial using circle time games to improve behavioral self-regulation in preschool. *Early Education and Development*, *22*, 489–519. https://doi.org/10.1080/10409289.2011.574258

Tsujimoto, S., Kuwajima, M., & Sawaguchi, T. (2007). Developmental fractionation of working memory and response inhibition during childhood. *Experimental Psychology*, *54*, 30–33. https://doi.org/10.1027/1618-3169.54.1.30

Vygotsky, L. S. (1978). *Mind in society: The development of higher mental processes*. Cambridge, MA: Harvard University Press.

Wass, S. V. (2015). Applying cognitive training to target executive functions during early development. *Child Neuropsychology*, *21*, 150–166. https://doi.org/10.1080/09297049.2014.882888

Wass, S. V., Cook, C., & Clackson, K. (2017). Changes in behaviour and salivary cortisol following targeted cognitive training in typical 12-month-old infants. *Developmental Psychology*, *53*, 815–825.

Wass, S. V., Porayska-Pomsta, K., & Johnson, M. H. (2011). Training attentional control in infancy. *Current Biology*, *21*, 1543–1547. https://doi.org/10.1016/j.cub.2011.08.004

Wass, S. V., Scerif, G., & Johnson, M. H. (2012). Training attentional control and working memory–Is younger, better? *Developmental Review*, *32*, 360–387. https://doi.org/10.1016/j.dr.2012.07.001

Wechsler, D. (2005). *Wechsler Individual Achievement Test (WIAT–II UK)*. London, UK: Pearson.

Wiebe, S. A., Espy, K. A., & Charak, D. (2008). Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. *Developmental Psychology*, *44*, 575–587. https://doi.org/10.1037/0012-1649.44.2.575

Wiebe, S. A., Sheffield, T., Nelson, J. M., Clark, C. A. C., Chevalier, N., & Espy, K. (2011). The structure of executive function in 3-year-olds. *Journal of Experimental Child Psychology*, *108*, 436–452. https://doi.org/10.1016/j.jecp.2010.08.008

Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Table S1. Pearson's Correlations for All Measures at 3 Months Across All Children

Table S2. Pearson's Correlations for All Measures at 6 Months Across All Children

Table S3. Pearson's Correlations for All Measures at 1 Year Across All Children

Table S4. Mean, Standard Deviation and Effect Size (Cohen's *d*) of Socioeconomic Status on Executive Functions, Mathematical Skills and Classroom Engagement at 3 Months for All Children

Table S5. Mean, Standard Deviation and Effect Size (Cohen's *d*) of Socioeconomic Status on Executive Functions, Mathematical Skills and Classroom Engagement at 6 Months for All Children

Table S6. Mean, Standard Deviation and Effect Size (Cohen's *d*) of Socioeconomic Status on Executive Functions, Mathematical Skills and Classroom Engagement at 1 Year for All Children

Appendix S1. CONSORT 2010 Checklist of Information to Include When Reporting a Randomised Trial