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Blakey, E. orcid.org/0000-0003-3685-3649, Matthews, D., Cragg, L. et al. (7 more authors) (2020) The role of executive functions in socioeconomic attainment gaps : results from a randomized controlled trial. Child Development, 91 (5). pp. 1594-1614. ISSN 0009-3920

https://doi.org/10.1111/cdev.13358

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

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The authors have no conflict of interest to declare.

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Note: this paper has been accepted for publication in *Child Development.* Please cite as: Blakey, Matthews, Cragg, Buck, Cameron, Higgins, Pepper, Ridley, Sullivan & Carroll (in press). The Role of Executive Functions in Socioeconomic Attainment Gaps: Results from a Randomized Controlled Trial. *Child Development.*

Abstract

The socioeconomic attainment gap in mathematics starts early and increases over time. The present 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 pre-registered and followed CONSORT guidelines. Executive functions and mathematical skills were measured at baseline, one week, three months, six months and one year post-training. Executive functions mediated the relation between SES 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.

Introduction

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 the present 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 randomised 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 such, can be measured in several ways through household income, parent education and family neighbourhood (Leventhal & Brooks-Gunn 2000). All these indicators have been associated with cognitive and health outcomes (Adler & Snibbe, 2003). For example, family neighbourhood is associated with health, academic attainment, and behavioral 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 than their higher-SES peers, and this gap widens over the first four 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., 2001). 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, 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 through 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 large 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 et al., 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 linked with executive function development (Gooch et al., 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 et al., 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 minimise 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, 2012; 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, Linqvist, Nutley, Bohlin & Klingberg, 2009; Wass, Cook & Clackson, 2017; Wass, Porayska-Pomsta & Johnson, 2011) and with young *and* diverse samples (Goldin et al., 2014; Ballieux et al., 2016) 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.

The present study had three aims: firstly, to determine whether differences in executive function skills can explain the SES attainment gap in 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 randomised control trial 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, and 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 the present 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 pre-registered and followed CONSORT guidelines; and we examined transfer to very different, non-trained tasks up to one 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., 2009), 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 et al., 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., 2017; Wass et al., 2011). Finally, the duration of training has been shown to have little impact on the extent of transfer (Karbach & Verhaeghen, 2014; Melby-Lervåg, Redick & Hulme, 2016; Sala & Gobet, 2017), suggesting that shorter training interventions should be prioritised, 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 for 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 hypothesised 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 neighbourhoods 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 (Garon et al., 2008; Chevalier et al., 2012) that have been found to consistently relate to children's foundational mathematical skills (Cragg & Gilmore., 2014; Raghubar, Barnes & Hecht, 2010). The baseline tasks were repeated at post-test and at follow-ups over one year, enabling us to examine if any transfer was maintained over a longer period of time.

Method

Participants

Initially, 196 3- to 4-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 favour 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 testing). The final sample comprised 175 children (M_{ag} = 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 neighbourhood 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 neighbourhoods 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 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 categorised 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 groups had comparable SES profiles: in the training group, 55 children were from low-SES backgrounds and 32 children were from high-SES backgrounds. 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, this education data was 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), $X^2(N = 175) = 4.20$, $p = .04$. Therefore, this information is reported as descriptive information only.

Design

This study used a randomised control trial (RCT) with a pretest-posttest design following CONSORT guidelines (see the Appendix for the CONSORT checklist). The RCT was pre-registered at clinicaltrials.gov (ID: NCT03063411). Recruitment started in January 2017 and testing took place between March 2017 and April 2018 when the one-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 computerised tasks lasting 20 minutes, once a week for four 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: one week post-training, three months post-training, six months post-training and one year post-training. A measure of receptive vocabulary was included at baseline. In addition, to examine if training transferred to classroom behaviour, teachers rated children's classroom engagement at baseline and then again at three months, six months, and one year post-training. Teachers and parents were blind to the child's group. The study received ethical approval from the University's Psychology ethics sub-committee. 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, USA). 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 et al., 1997) and the One-back task (Tsujimoto et al., 2007); and two tasks involved inhibitory control: interference control (the Flanker task, Rueda et al., 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 minutes. Tasks were adaptive: they increased in difficulty 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 4000ms. The ISI increased by 2000ms (to a maximum of 8000ms) 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 2000ms 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 1000ms. The ISI duration increased by 1000ms (to a maximum of 3000ms) 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 4000ms, with an ISI of 1000ms. 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 1000ms (to a minimum of 2000ms). 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 2500ms. If children were accurate on 75% or more of no-go trials, this time reduced by 500ms (to a minimum of 1500ms).

The Active Control Group

The control group completed three tasks that required children to make simple perceptual judgements. 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 (for example, "Press the animal that can fly"); and the third task required children to search for a particular image amongst distractors (for example, "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 post-test tasks

To assess training improvements to mathematical skills and executive functions, different, non-trained tasks were administered at baseline and post-test 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 twelve 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 twelve 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 twelve trials in a pseudo-random 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 et al., 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 twelve trials in a fixed pseudo-random 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 sub-test of the Wechsler Individual Achievement Test-II battery was used to measure mathematical skills (Wechsler, 2005). The Mathematical Reasoning subtest is a reliable and standardised 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 sub-test of the Wechsler Individual Achievement Test-II battery was used to measure vocabulary (Wechsler, 2005). This reliable and standardised 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 et al., 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, three months, six months and at one year post-test. 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 the supplementary materials (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 controls, 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 the supplementary materials and show a pattern similar to that 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. To assess model fit we used a range of recommended fit indices: the χ^2 statistic (as a global indication of model fit), the comparative fit index (CFI), the standardised 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 < 0.06 (Hu & Bentler, 1999). As models were nested, the χ^2 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 (χ^2 = .63, df = 2, CFI = 1.0, SRMR = .013, RMSEA = .00). The two-factor model also fit the data well (χ^2 = .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 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; Wiebe et al., 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: .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: .28, 2.73].

The Effect of the Intervention

Age ($t(173) = .12$, $p = .908$), gender (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* = .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 ($M = 3.63$, $SD = .68$) and the active control group ($M = 3.73$, $SD = .52$), 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 non-trained 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 ($N = 63$) = .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 ($N = 63$) = .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) = .03, $p = .856$.

The critical test was whether the training intervention improved children's performance on different, non-trained measures. In the primary analyses, we ran ANCOVAs 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 post-training time points. There was no effect of training on working memory at post-test ($F(1,168) = .29$, $p = .594$, $\eta^2_p = .002$), three months ($F(1,167) = .35$, $p = .557$, $\eta^2_p = .002$), six months ($F(1,147) = .83$, $p = .363$, $\eta^2_p = .006$) or one year ($F(1,144) = .28$, $p = .598$, $\eta^2_p = .002$). There was no effect on short-term memory at post-test ($F(1,168) = .17$, $p = .683$, $\eta^2_p = .001$), three months ($F(1,168) = .19$, $p = .662$, $\eta^2_p = .001$), six months ($F(1,147) = .10$, $p = .749$, $\eta^2_p = .001$) or one year ($F(1,144) = 1.09$, $p = .298$, $\eta^2_p = .01$). There was no effect on inhibitory control at post-test (Peg Tapping: $F(1,166) = 1.44$, $p = .231$, $\eta^2_p = .01$; Stroop: $F(1,168) = .007$, $p = .935$, $\eta^2_p < .001$), three months (Peg Tapping: $F(1,166) = 1.22$, $p = .271$, $\eta^2_p = .01$; Stroop: $F(1,166) = .66$, $p = .419$), six months (Peg Tapping: $F(1,146) = 2.55$, $p = .112$, $\eta^2_p = .02$; Stroop: $F(1,147) = .54$, $p = .464$, $\eta^2_p = .004$) or one year (Peg Tapping: $F(1,143) = .14$, $p = .706$, $\eta^2_p = .001$; Stroop: $F(1,144) = .13$, $p = .723$, $\eta^2_p = .001$). There was no effect on mathematical reasoning at post-test ($F(1,169) = .26$, $p = .612$, $\eta^2_p = .002$), three months ($F(1,168) = 2.38$, $p = .125$, $\eta^2_p = .01$), six months ($F(1,147) = .80$, $p = .374$, $\eta^2_p = .005$) or one year ($F(1,144) = .97$, $p = .328$, $\eta^2_p = .01$). There was no effect on classroom engagement at three months ($F(1,170) < .001$, $p = .994$, $\eta^2_p < .001$), six months ($F(1,145) = 1.62$, $p = .205$, $\eta^2_p = .01$) or one year ($F(1,144) = .08$, $p = .777$).

As planned secondary analyses, we added an SES x 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 ($F_{MAX}(1,168) = 2.71$, $p = .101$; $F_{MIN}(1,166) = .008$, $p = .930$).There was a small but marginally significant interaction between group and

SES for working memory at one year post-test, $F(1, 142) = 3.81$, $p = .053$, = .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, $p = .006$ [.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} = .75, $p = .061$ [-.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} = -.24, $p = .447$ [-.85, .38]. To examine this interaction further, we ran a Bayesian ANCOVA model in JASP v8 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 x 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 (BF10 = 0.28) (see Table 4), suggesting that there was more evidence for there being no interaction between group and SES for working memory at one year post-test

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 diverse sample of preschoolers, and then tested this prediction causally by running an RCT to test whether executive function training would narrow the attainment gap up to one 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 the present 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 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., 2017), 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 behaviours 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 behaviours 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 towards 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 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, the present 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. The present 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 et al., 2014). Higher-SES parents may have more resources to engage in home learning activities, and generally report more positive attitudes towards 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 the present 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; Cragg & Gilmore, 2014; Clark, Pritchard & Woodward, 2010). In the present 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 (LeFevre et al., 2010; Geary, 2004). 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 hypothesised 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 non-trained 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 (Dunning, Holmes & Gathercole, 2013; Ang, Lee, Cheam, Poon & Koh, 2015). 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, the present 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 hypothesised 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, 2011) 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 computerised 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, 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 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, Reduck & Hulme, 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 the family and 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 integrate more intensive interventions into classrooms do tend to find 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 meta-cognition are more helpful while executive functions are still developing as they provide 'shortcuts' that can compensate for rudimentary skills. Strategies and meta-cognition 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 a more 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 programme 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 whilst they are engaging in the learning activities themselves and whilst 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, 2007). 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 poorer executive functions to begin with.

In summary, the current 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. The present 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.

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Tables and Figures

Table 1. Pearson's correlations for all measures at baseline

	M (SD)	BWS	Corsi	Peg Tap	Stroop	Maths	CE	Vocab
BWS	1.05(1.18)							
Corsi	3.58(1.81)	.15*						
Peg Tap	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. * p < .05, ** p < .01, *** p < .001. BWS = backwards word span; Stroop = black-white Stroop; CE = classroom engagement; vocab = receptive vocabulary.

Table 2. Mean, standard deviation (*SD*) and effect size (cohen's *d*) of SES on executive functions, mathematical skills, classroom engagement and vocabulary at baseline for all children.

	Low-SES	**HighSES**	
	M (SD)	*M* (SD)	*d*
BWS	0.92(1.08)	1.25(1.31)	.28
Corsi	3.59(1.71)	3.55(1.97)	.02
Peg Tap	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.

Table 3. Means and standard deviations (*SDs*) for each measure by each group and for the baseline, post-test and three-, six- and one-year post-test assessments.

	Executive Function Training Group					**Active Control Group**				
	Baseline	Post-test	3 months	6 months	One year	Baseline	Post-test	3 months	6 months	One 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.

Table 4. Means and standard deviations (*SDs*) at each post-test 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**			
	Post-test	3months	6months	1 year	Post-test	3months	6months	1 year	Post-test	3months	6months	1 year	Post-test	3months	6months	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 Tap	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 (.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.

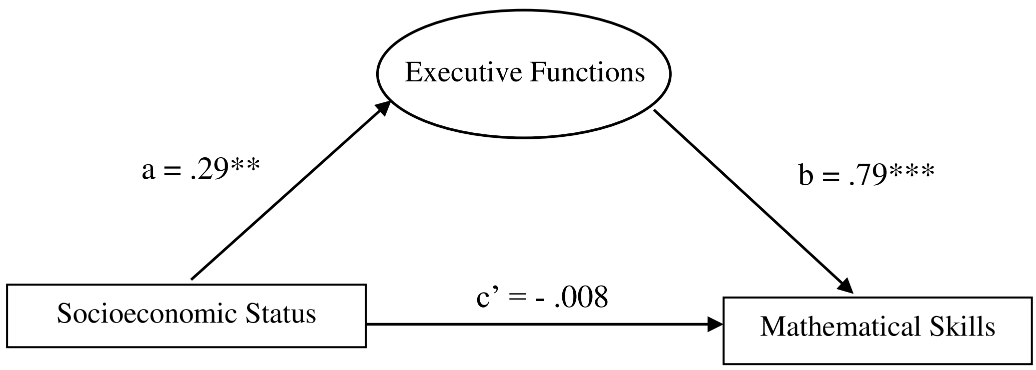
Table 5. Bayes factors for group, SES and the interaction with working memory one year later controlling for baseline working memory.

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

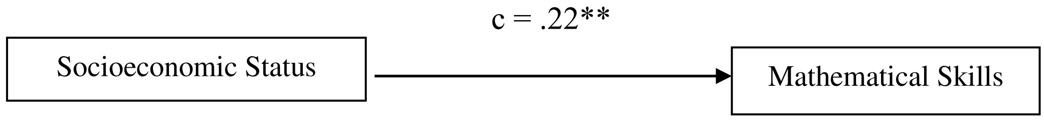
Note. All models include working memory at baseline.

Figure 2. Mediation model showing the relation between SES and mathematical skills as mediated by executive functions at baseline. Standardized beta weights are given.

Mediated Model with Indirect Effect:



Total Effect Model:



Note. Asterisks indicate significant coefficients (*p < .05, **p < .01, ***p < .001).

Figure 1. Flow of participants through the trial.