Developmental Science

Developmental Science (2015), pp 1–17 DOI: 10.1111/desc.12246

PAPER

Socioeconomic status and executive function: developmental trajectories and mediation

Daniel A. Hackman,[1] Robert Gallop,[2] Gary W. Evans[3] and Martha J. Farah[1]

1. *Center for Cognitive Neuroscience, Center for Neuroscience and Society, Department of Psychology, University of Pennsylvania, USA*
2. *Department of Mathematics and Applied Statistics, West Chester University, USA*
3. *Departments of Design and Environmental Analysis and Human Development, Bronfenbrenner Center for Translational Research, Cornell University, USA*

Abstract

*Childhood socioeconomic status (SES) predicts executive function (EF), but fundamental aspects of this relation remain unknown: the developmental course of the SES disparity, its continued sensitivity to SES changes during that course, and the features of childhood experience responsible for the SES–EF relation. Regarding course, early disparities would be expected to grow during development if caused by accumulating stressors at a given constant level of SES. Alternatively, they would narrow if schooling partly compensates for the effects of earlier deprivation, allowing lower-SES children to 'catch up'. The potential for later childhood SES change to affect EF is also unknown. Regarding mediating factors, previous analyses produced mixed answers, possibly due to correlation amongst candidate mediators. We address these issues with measures of SES, working memory and planning, along with multiple candidate mediators, from the NICHD Study of Early Childcare (*n *= 1009). Early family income-to-needs and maternal education predicted planning by first grade, and income-to-needs predicted working memory performance at 54 months. Effects of early SES remained consistent through middle childhood, indicating that the relation between early indicators of SES and EF emerges in childhood and persists without narrowing or widening across early and middle childhood. Changes in family income-to-needs were associated with significant changes in planning and trend-level changes in working memory. Mediation analyses supported the role of early childhood home characteristics in explaining the association between SES and EF, while early childhood maternal sensitivity was specifically implicated in the association between maternal education and planning. Early emerging and persistent SES-related differences in EF, partially explained by characteristics of the home and family environment, are thus a potential source of socioeconomic disparities in achievement and health across development.*

Research highlights

- Lower family socioeconomic status (SES) predicts worse performance on tasks of executive function at the youngest age measured, in early childhood.
- Family SES does not predict the rate of growth of executive function across early and middle childhood, and thus SES differences persist without accumulating or diminishing.
- However, increases or decreases in a family's income-to-needs ratio are accompanied by corresponding changes in planning.
- Characteristics of the home and family environment explain part of the association between SES and executive function.

Introduction

Determining the relation between socioeconomic status (SES) and the development of executive function (EF) is a promising strategy for understanding how childhood SES influences achievement, health, and psychosocial development (Hackman, Farah & Meaney, 2010;

Address for correspondence: Daniel A. Hackman, Department of Population Health Sciences, University of Wisconsin, 610 Walnut Street, Rm. 707 WARF Bldg., Madison, WI 53726-2397, USA; e-mail: dhackman@wisc.edu

Raizada & Kishiyama, 2010). SES, particularly early in childhood, is consistently associated with cognitive development as measured by psychometric tests and academic achievement (Bradley & Corwyn, 2002; Brooks-Gunn & Duncan, 1997; McLoyd, 1998; P. Miller, Votruba-Drzal & Setodji, 2013; Sirin, 2005). EF is a foundational ability for cognitive development, decision-making, and achievement, and is a critical predictor of school readiness and school achievement (Alloway & Alloway, 2010; Blair, 2013; Bull, Espy & Wiebe, 2008; A.R.A. Conway, Kane & Engle, 2003; Daneman & Merikle, 1996; St Clair-Thompson & Gathercole, 2006; Ursache, Blair & Raver, 2012).

EF is a collection of cognitive abilities that are involved in flexible, goal-directed behavior and are dependent on the prefrontal cortex (PFC) (Best & Miller, 2010; E.K. Miller & Cohen, 2001; Zelazo, Carlson & Kesek, 2008). Although there is some evidence that the factor structure of EF may be different in children (Best & Miller, 2010; Huizinga, Dolan & van der Molen, 2006; Wiebe, Espy & Charak, 2008), it is thought to be composed of three distinct but correlated factors of inhibitory control, working memory (updating), and shifting (Miyake, Friedman, Emerson, Witzki, Howerter & Wager, 2000) that continue to develop throughout childhood and into adolescence (Best & Miller, 2010; Huizinga *et al*., 2006). Working memory refers to the active, short-term maintenance and manipulation of information (Baddeley, 2003; Best & Miller, 2010; Miyake *et al*., 2000). Shifting concerns the ability to flexibly switch between sets of behaviors or tasks, rules, or mental states, while inhibition refers to the intentional inhibition of a prepotent response that is often performed automatically (Best & Miller, 2010; Miyake *et al*., 2000). A more complex aspect of executive function, planning, is strongly related to inhibitory control and involves identifying a goal and both planning and executing the steps needed to attain that goal (Huizinga *et al*., 2006; Miyake *et al*., 2000). Planning also continues to develop into early adulthood (Albert & Steinberg, 2011).

Working memory and planning, the executive functions that are the focus of this study, have both been implicated in academic achievement as well as in health and development more broadly. Working memory plays an important role in the development of mathematical skills and reading comprehension (Alloway & Alloway, 2010; Alloway, Gathercole, Adams, Willis, Eaglen & Lamont, 2005; Bull *et al*., 2008; Daneman & Merikle, 1996; St Clair-Thompson & Gathercole, 2006), while planning is similarly predictive of achievement, particularly for mathematics (Bull *et al*., 2008; Clark, Pritchard & Woodward, 2010; Crook & Evans, 2014). Working memory and planning are also associated with emotional functioning (Ochsner & Gross, 2008; Snyder, 2013) as well as health behaviors such as those related to nutrition and physical activity (Pentz & Riggs, 2013; Riggs, Chou, Spruijt-Metz & Pentz, 2010; Wong & Mullan, 2009). Moreover, planning is a central component of theories concerning the development of health behavior as well as health behavior change (Azjen, 1991; Blume & Marlatt, 2009). Consequently, SES differences in the development of working memory and planning, and the mechanisms by which such differences arise, are likely to have significant consequences for disparities in academic achievement and health development.

SES and executive function

An emerging literature has documented the association between different indicators of SES and EF (for review, Hackman & Farah, 2009). Multiple studies have reported SES-related disparities on composite or latent measures of EF in children as young as 2 years old through age 5 (Blair, Granger, Willoughby, Mills-Koonce, Cox, Greenberg, Kivlighan, Fortunato & the FLP Investigators, 2011; Hughes, Ensor, Wilson & Graham, 2010; Noble, Norman & Farah, 2005; Raver, Blair & Willoughby, 2013; Rhoades, Greenberg, Lanza & Blair, 2011; Wiebe, Sheffield, Nelson, Clark, Chevalier & Espy, 2011). Regarding individual tasks or components, lower-SES children have been found to perform worse on tasks of inhibitory control, working memory, executive attention, flexibility, and planning (Lipina, Martelli, Vuelta & Colombo, 2005; Lipina, Martelli, Vuelta, Injoque-Ricle & Colombo, 2004; Mezzacappa, 2004; Noble, McCandliss & Farah, 2007; cf. Engel, Santos & Gathercole, 2008). In middle childhood, SES-related disparities have been observed for working memory, inhibitory control, cognitive flexibility, and attention (Ardila, Rosselli, Matute & Guajardo, 2005; Farah, Shera, Savage, Betancourt, Giannetta, Brodsky, Malmud & Hurt, 2006; Sarsour, Sheridan, Jutte, Nuru-Jeter, Hinsh & Boyce, 2011), while Evans and Schamberg (2009) found that the duration of poverty throughout development was inversely related to working memory at age 17, suggestive of possible chronic effects of poverty. Moreover, SES differences in PFC activation and cortical structure have been reported (D'Angiulli, Herdman, Stapells & Hertzman, 2008; Jednorog, Altarelli, Monzalvo, Fluss, Dubois, Billard, Dehaene-Lambertz & Ramus, 2012; Kishiyama, Boyce, Jimenez, Perry & Knight, 2009; Noble, Houston, Kan & Sowell, 2012; Sheridan, Sarsour, Jutte, D'Esposito & Boyce, 2012; Stevens, Lauinger & Neville, 2009), indicative of possible SES differences in the neural substrates underlying executive function.

SES and trajectories of EF development

Despite the cross-sectional association just reviewed, it remains unclear at what age SES differences in EF emerge and whether SES affects the rate of EF development throughout childhood and adolescence. Do SES disparities in EF widen as differences in experience accumulate? Do the disparities narrow, perhaps as a result of school experience compensating for earlier SES-linked differences in experience? Or does early childhood SES set children on a trajectory of EF development that, barring changes in SES, results in a constant disparity over time?

The protracted development of both EF performance (Albert & Steinberg, 2011; Best & Miller, 2010; Huizinga *et al*., 2006) and the PFC (Gogtay, Giedd, Lusk, Hayashi, Greenstein, Vaituzis, Nugent, Herman, Clasen, Toga, Rapoport & Thompson, 2004; Shaw, Kabani, Lerch, Eckstrand, Lenroot, Gogtay, Greenstein, Clasen, Evans, Rapoport, Giedd & Wise, 2008) suggests that EF may remain sensitive to experience throughout this period. Evans and Schamberg's (2009) finding, that the duration of poverty predicts working memory, suggests a progressive widening of SES disparities as disadvantage is compounded over time. However, if the duration of poverty is confounded with the timing and severity of poverty, as seems likely, then these data do not necessarily indicate that SES disparities grow with time. The ideal evidence for addressing this question, longitudinal data with common measures within individuals across development, is limited. One study of EF examined longitudinal change in SES disparities over time in early childhood, finding that SES did not predict change over time between the ages of 4 and 6 (Hughes *et al*., 2010). A more recent study, focused on working memory, found that SES disparities remained constant from later childhood through adolescence (Hackman, Betancourt, Gallop, Romer, Brodsky, Hurt & Farah, 2014). Concerning trajectories of EF development across childhood and adolescence, much remains to be learned. Understanding when this relation emerges and how it changes over time can provide critical guidance for identifying the mechanisms underlying these differences and, ultimately, for interventions to prevent or reverse them (Shonkoff, Boyce & McEwen, 2009).

Potential mediators of the SES–EF association: the challenge of correlated candidate mediators

What causes SES disparities in EF? Two common models of social causation are the family stress model and the family investment model (Conger & Donnellan, 2007). In the family stress model, economic stress affects development by influencing the quality, sensitivity, and responsivity of caregiving practices. In the family investment model, SES affects development by way of the learning resources, environment, opportunities, and time and guidance parents provide. A wealth of data from animal models as well as from developmental psychology and neuroscience indicate that parental care and the home environment impact both the development of brain regions involved in executive function as well as overall cognitive and behavioral development, lending credence to the plausibility of these models (for review see Hackman *et al*., 2010).

Such models have support in the wider literature focusing on determinants of executive function. One aspect of parenting that has received broad attention is scaffolding, or parental support and guidance in age-appropriate problem-solving, which includes a sensitive understanding of when to step in and help (Bernier, Carlson & Whipple, 2010; Hammond, Muller, Carpendale, Bibok & Lieberman-Finestone, 2012). Multiple studies have found evidence for a positive association between scaffolding and EF performance (Bernier, Carlson, Deschenes & Matte-Gagne, 2012; Bernier *et al*., 2010; Bibok, Carpendale & Muller, 2009; Hammond *et al*., 2012; Hughes & Ensor, 2009; Landry, Miller-Loncar, Smith & Swank, 2002), although attachment security predicts EF independently from scaffolding (Bernier *et al*., 2012). A lack of learning resources in the home has been shown to predict a delay in inhibitory control and cognitive flexibility through kindergarten (Clark, Sheffield, Chevalier, Nelson, Wiebe & Espy, 2013) and strategies to maintain or redirect children's attentional focus have also been shown to predict EF performance (A. Conway & Stifter, 2012; Eigsti, Zayas, Mischel, Shoda, Ayduk, Dadlani, Davidson, Aber & Casey, 2006).

Although this lends strong theoretical support to the family stress and family investment models as mediators of SES effects, alternative risk factors also predict EF. The chronic, cumulative physical and psychosocial stressors experienced by children in poverty (Evans & Kim, 2013) also are likely to influence PFC development and EF via their impact on stress response systems (e.g. Arnsten, 2009). Moreover, low birthweight and early gestational age, which are both related to SES (Bradley & Corwyn, 2002) have been linked to broad differences in neurobehavioral development and executive function, particularly in extreme cases (Aarnoudse-Moens, Weisglas-Kuperus, van Goudoever & Oosterlaan, 2009; Espy, Stalets, McDiarmid, Senn, Cwik & Hamby, 2002; Hackman *et al*., 2010; Luu, Ment, Allan, Schneider & Vohr, 2011). Moreover, maternal depression and parental stress during infancy have been identified as potential risk factors for disruptions in parent–child relationships, cognitive development, and executive function in particular (Beck, 2001; Grace, Evindar & Stewart, 2003; Hughes, Roman, Hart & Ensor, 2013; McLoyd, 1998)

To date, studies aimed at identifying the mediators of the association between SES and EF show mixed findings overall, with some support for parenting practices for early childhood EF (Blair *et al*., 2011), allostatic load for EF in adolescence (Evans & Schamberg, 2009) and the home environment (Sarsour *et al*., 2011). However, it is difficult to meet the assumption in such analyses that no unmeasured candidate mediators have been omitted from the model (Baron & Kenny, 1986; MacKinnon, 2008). There are many candidate mediators, including the aforementioned candidates as well as many other correlated differences in family, neighborhood, and societal experiences (Bradley & Corwyn, 2002; Evans, 2004). None of the previous mediation analyses simultaneously include measures of parenting, stress, and the home environment to determine whether such pathways are truly specific. Consequently, despite the plausibility of these pathways, their specificity has not been established.

Current study

In this study, our first aim was to address critical unanswered questions concerning the trajectory of EF development as a function of both early childhood SES and later changes in SES. Specifically, we ask (a) whether early SES measures are associated with differences in the rates of development of working memory and planning in addition to overall performance level, with trajectories either diverging or converging over time, and (b) whether changes in family socioeconomic circumstances later in childhood also predict working memory and planning, independent of early childhood SES, such that a rise in family income later in childhood would tend to lift child performance. To address these questions, we employed data from the National Institute of Child Health and Development Study of Early Child Care (NICHD SECCYD), in which working memory and planning were measured at different ages from early childhood through the elementary school, with sufficient variability in performance present at each assessment.

Our second aim in this study was to identify specific, dissociable mechanisms underlying the association between SES and both working memory and planning. In order to do so, we conducted multilevel mediation analyses (Krull & MacKinnon, 2001) with multiple candidate mediators from the NICHD SECCYD dataset, which offers a wealth of socioeconomic and environmental measures across time, while adjusting each candidate mediator for the variance predicted by the others to identify a separate and unique component for each mediator. We tested the roles of home environment quality, maternal sensitivity, and life stress as independent mediators distinct from indicators of prenatal and neonatal health as well as parent stress and maternal depression in early infancy.

Methods

Study population

Participants were drawn from the National Institute of Child Health and Development Study of Early Child Care (NICHD SECCYD), a multi-site, prospective study with an original enrollment of 1364 children. Complete details concerning data collection, exclusion criteria, and enrollment are available online (http://www.icpsr.umich.edu/icpsrweb/ICPSR/series/233). The subsample in the current analysis includes those children who had at least one measure of EF and complete data for person-level and time-varying predictors employed in the analyses. The total sample included 1009 children and families. Table 1 summarizes the characteristics of the total sample. The Institutional Review Board of the University of Pennsylvania approved the current analysis.

Predictors: measures of socioeconomic status

Income-to-needs was measured as the ratio between total family income, including government assistance, and the poverty threshold, accounting for the size of the household. Early income-to-needs was defined as the average from assessments at 1, 6, 15, 24, and 36 months old, natural log transformed. In addition, we examined change in family income-to-needs relative to early childhood (Singer & Willett, 2003), created by subtracting the early childhood average from measures concurrent with EF assessments.

Maternal education was measured at 1 month of age using the following rubric: less than a high school graduate = raw number of years of education; high school graduate or completion of the General Educational Development (GED) test = 12; AA degree, some college, or vocational school = 14; Bachelor's degree = 16; Master's degree or some graduate work = 18; Law degree = 19; Doctoral-level degree (i.e. EdD, MD, PhD, etc.,) = 21.

Executive function

Analyses focused on working memory and planning, and Table 2 presents the mean performance level for the

Table 1 *Sample and mediator characteristics (n = 1009)*

	n (%)	*M* (*SD*)
Income-to-needs ratio (family, average through 36 months)		3.6 (2.7)
Maternal education		14.5 (2.4)
Less than high school	74 (7.3)	
High school graduate	202 (20.0)	
A.A. degree, some college	335 (33.2)	
Bachelor's degree	235 (23.3)	
Master's degree	135 (13.4)	
Law degree	10 (1.0)	
Doctoral-level	18 (1.8)	
Gender		
Male	506 (50.1)	
Female	503 (49.9)	
Race / Ethnicity		
White	844 (83.6)	
African-American	108 (10.7)	
Asian / Pacific Islander	15 (1.5)	
American Indian ...	2 (0.2)	
Other	40 (4.0)	
Hispanic / Latino	55 (5.5)	
Maternal Vocabulary (PPVT)		99.8 (18.3)
Mediators		
Birthweight (g)		3499.2 (516.8)
Gestational age (weeks)		39.3 (1.4)
Maternal depression, 1 month		11.0 (8.6)
Negative life events, ratings, 54 months		5.7 (6.7)
Parent Stress,		
1 month (*n* = 1008)		53.3 (10.6)
6 months (*n* = 997)		50.2 (9.7)
HOME, 6 months (*n* = 1000)		
Enrichment		6.6 (1.9)
HOME, 15 months (*n* = 999)		
Enrichment		7.0 (1.4)
HOME, 36 months (*n* = 998)		
Learning materials		7.3 (2.4)
Academic stimulation		3.4 (1.2)
Variety		6.9 (1.5)
HOME, 54 months (*n* = 990)		
Learning materials		9.5 (1.5)
Academic stimulation		3.9 (1.1)
Variety		7.4 (1.3)
Maternal sensitivity		
6 months (*n* = 995)		9.3 (1.8)
15 months (*n* = 1000)		9.5 (1.6)
24 months (*n* = 981)		9.4 (1.7)
36 months (*n* = 1,002)		17.3 (2.7)
54 months (*n* = 985)		17.1 (2.8)

Table 2 *Executive function performance*

Task	*M* (*SD*)
Memory for sentences, W Score	
54 months (*n* = 981)	457.5 (18.2)
1st Grade (*n* = 897)	482.0 (13.8)
3rd Grade (*n* = 840)	495.4 (13.9)
Tower of Hanoi, Planning Efficiency	
1st Grade (*n* = 868)	14.7 (7.2)
3rd Grade (*n* = 842)	23.3 (7.8)
5th Grade (*n* = 841)	29.1 (7.7)

working memory and planning tasks at each wave of assessment.

Working memory

Working memory was assessed with the Memory for Sentences subtest of the Woodcock-Johnson Psycho-educational Battery – Revised, Tests of Cognitive Ability (WJ-R COG; Woodcock, 1990; Woodcock & Johnson, 1989) at 54 months, Grade 1, and Grade 3. In this test a series of words, phrases, and sentences of increasing length and difficulty are presented orally and the child is asked to repeat exactly what was presented. Children can earn 2 points by repeating the item precisely, 1 point for responses with one error, and zero points for responses with two or more errors. Errors include word omission or substitution, the addition or omission of sounds at the end of words, or a change in word sequence. Children were administered the same task at all ages, which consists of 32 possible items, although the starting point varies by age. Children must establish a basal level of performance, either the lowest set of 4 perfect responses or the first item of the test. The test is discontinued after children obtain a score of zero on four consecutive items or the last item of the test is administered. The *W* score, a transformation of the Rasch ability scale centered on a value of 500, was employed in analyses. The *W* score is not standardized for relative rank and is an equal interval scale, making it appropriate for use in examining growth over time. The analysis included 1005 participants, with the majority completing all three assessments (*n* = 763, 75.9%), while 187 and 55 completed two and one assessments, respectively.

Planning

Planning and problem-solving abilities were assessed in Grades 1, 3 and 5 with the Tower of Hanoi (Welsh, Pennington, Ozonoff, Rouse & McCabe, 1990; Welsh, 1991), which requires that children plan an organized sequence of moves and find the most efficient strategy for solving a problem. Children are presented with a set of three vertical pegs and a set of rings of varying diameter. Rings are initially configured on the pegs, and the child is given a goal state, a tower in which the rings are ordered on one of the pegs with the largest ring on the bottom and the smallest on top. The child is then asked to move the rings into the goal state, using the fewest possible moves according to a set of rules. Children must successfully complete a problem with the fewest possible moves twice in succession before progressing to the next problem. If a rule is violated it is explained and a new trial is started. Once children fail a problem, the task is complete. Each problem had a maximum of six trials with no more than 20 moves per trial permitted. A score of 6 was given if the problem was successfully completed on the first two trials, a 5 was given if it was successfully completed on the second and third trials, and so on. Children could receive a score of 6, 5, 4, 3, 2, or 0 on any problem, and scores on individual test problems were summed to yield one total planning efficiency score (Borys, Spitz & Dorans, 1982). All valid scores for which remedial practice items were not administered or passed were included. This analysis thus included 971 participants, with the majority completing all three assessments (n = 689, 71.0%), while 200 and 82 completed two and one assessments, respectively.

In first grade there were four problems that use three rings, and two problems that use four rings, ranging in difficulty from a three-ring configuration that can be completed in four moves to a four-ring configuration that can be solved with 11 moves (Items 1–6). In third and fifth grade, two changes were made. Item 1 from first grade was omitted, given that 78.7% of participants achieved a perfect score of 6 on Item 1 in first grade (M = 5.57, SD = 1.06) and it was thus assumed that all children would solve the first task efficiently. In addition, the ceiling of the task was expanded by adding an additional four-ring configuration that could be solved with 15 moves (thus Items 2–7 were administered, assuming all would have passed Item 1). Consequently, we made two adjustments to the planning efficiency scores to ensure that scores were comparable across ages and the change in measurement approach did not introduce any bias. First, as the final item was not administered in first grade, we estimated that those who passed the sixth item in first grade would have obtained an equivalent score on the final item had it been administered. This adjustment applied only to the 48 (4.4%) participants included in the analysis who passed the sixth item in first grade; for the other 95.6% percent of participants there would be no differences in their total score even if Item 7 had been administered. Second, we accounted for possible variation in scores on Item 1 in Grades 3 and 5, should it have been administered and not everyone achieved a perfect score. Instead of simply adding a perfect score of 6 for the basal item in third and fifth grade, as assumed by the change in test structure, we used performance on Items 2–6, common across all assessment points, to impute a score on Item 1 for Grades 3 and 5. To do so, we estimated a regression model employing data from first grade, using scores on Items 2–6 to predict the score on item 1. We then used the parameters of this regression model to predict scores on Item 1 at Grades 3 and 5 from performance on Items 2–6 during the assessments at that grade, while adding a random error term. Through this two-staged approach with random errors, we are deriving estimates termed Best Linear Unbiased Prediction (BLUP) estimates. BLUP estimates are: linear in the sense that they are linear functions of the data, unbiased in the sense that the average value of the estimates is equal to the average value of the quantity being estimated, best in the sense that they have the minimum mean squared error within the class of linear unbiased estimators, and prediction estimates to distinguish them from estimation of the random effects (Robinson, 1991). We completed 10 iterations of this BLUP estimation and employed the average predicted score on Item 1 for each individual in third and fifth grade. All estimates greater than 6 were reduced to a 6 so as not to exceed the maximum of the scale. A parallel approach was used by Jaffee and Gallop (2007) to address missingness to yield the most accurate estimate of what would have been acquired if the data had been available. Employing this procedure possible planning efficiency scores at each time point ranged from 0 to 42.[1]

Mediators

Measures

As an index of the family stress model, two composites of maternal sensitivity were created. Maternal sensitivity was measured during a semi-structured mother–child interaction (NICHD ECCRN, 1999) that took place at home at 6 and 15 months and in the laboratory at 24, 36 and 54 months. Independent raters coded videotapes of dyadic interactions with global 4-point rating scales at age 6, 15 and 24 months and 7-point rating scales at 36 and 54 months. Maternal sensitivity ratings were a composite of ratings for (a) maternal sensitivity to child nondistress, (b) intrusiveness (reversed), and (c) positive regard at 6, 15 and 24 months, and (a) supportive presence, (b) hostility (reversed), and (c) respect for autonomy at 36 and at 54 months. We created one composite for the infant and toddler period by averaging the z-scores for maternal sensitivity at 6, 15, and 24 months, and one for the early childhood period by

[1] We compared this approach to multiple combinations of approaches in which (a) no adjustment was made in first grade for possible scores on Item 7 and/or (b) scores for Item 1 in third and fifth grade were assumed to be a perfect score of 6 or were determined with the same regression-based approach but not including a random error term. In all cases the patterns of growth and the patterns of findings related to SES, as reported in the Results section, were equivalent, indicating that the results are robust and independent of the approach to handling the Tower of Hanoi data.

averaging the z-scores from the 36- and 54-month assessments.

As an index of the family investment model, the degree of home enrichment was measured with the Infant/ Toddler and Early Childhood versions of the Home Observation for Measurement of the Environment (HOME) Inventory (Caldwell & Bradley, 1984), a combination of a home observation and semi-structured interview that was administered at 6, 15, 36 and 54 months of age. Following the approach used by the NICHD Early Child Care Research Network (2005), we created an infant/toddler enrichment composite by averaging the z-scores from a factor derived at both the 6- and 15-month assessments that measures the degree of enrichment that parents provide in the home, including toys, books, and experiences that help them develop new skills. At 36 and 54 months, the home enrichment scale is based on an average of the z-scores for the Learning Materials, Variety, and Academic Stimulation subscales (NICHD, 2005), which we then averaged across the two assessments to create an early childhood home enrichment composite. Example items from the Learning Materials subscale include '10 or more children's books are available to the child' and '3 or more three puzzles are available to the child'. Example items from the Variety subscale include 'At least 1 musical instrument is available to the child' and 'Child has been taken to a museum during past year'. Examples from the Academic stimulation subscale include 'Child is encouraged to learn spatial relationships' and 'Child is encouraged to learn numbers'.

In addition, to determine the specificity of hypothesized pathways, we examined alternative mediators including stressful life events experienced by the family, birthweight, gestational age, postpartum depression, and parent stress in infancy. Stressful life events were measured using the sum of all negative event ratings, reverse scored, at 54 months via parent report with the Life Experiences Survey (Sarason, Johnson & Siegel, 1978). Birthweight was measured in grams and gestational age in weeks. Maternal depression at 1 month was measured with the total score from the Center for Epidemiological Studies Depression Scale (CES-D; Radloff, 1977). Parent stress was measured using a composite averaging z-scores from the 1- and 6-month measures of a modified, 30-item version of the Parenting Stress Index (Abidin, 1983).

Extracting unique variance

As indicated in Table 3, these nine candidate mediators are highly correlated, with the infant/toddler and early childhood composites for both maternal sensitivity and the home environment exhibiting particularly strong correlations (all $r > .4$, $p < .001$). Consequently, we ran a regression model for each potential mediator as predicted by the eight other mediators, and saved the unstandardized residual for use in mediation analyses. These adjusted mediators thus represent the unique variance in each mediator that is not shared with other potential mediators.

Control variables

Person-level variables for gender (female, n = 503, 49.9%), Hispanic / Latino ethnicity (n = 55, 5.5%), African-American racial identity (n = 108, 10.7%), and all other non-white racial or ethnic identities (n = 57)

Table 3 *Intercorrelation among potential mediators and measures of socioeconomic status (n = 1009)*

Measure	1	2	3	4	5	6	7	8	9	10	11
1. Birthweight	–										
2. Gestational age	.47***	–									
3. Maternal depression	−.02	.03	–								
4. Negative life events	.07*	.07*	.18***	–							
5. Parent stress	−.01	.07*	.50***	.10**	–						
6. Enrichment: Infant / Toddler	.10**	.01	−.23***	.02	−.10**	–					
7. Enrichment:Early Childhood	.05	−.02	−.24***	−.01	−.11**	.57***	–				
8. Maternal sensitivity: Infant / Toddler	.12***	−.02	−.24***	.01	−.12***	.48***	.46***	–			
9. Maternal sensitivity: Early childhood	.09**	−.05	−.21***	−.01	−.12***	.40***	.44***	.59***	–		
10. Early income-to-needs	.03	−.08*	−.24***	−.05	−.09**	.46***	.49***	.48***	.42***	–	
11. Maternal education	.07*	−.04	−.23***	−.03	−.06	.40***	.49***	.46***	.42***	.58***	–

* $p < .05$; ** $p < .01$; *** $p < .001$.

were included. Analyses included maternal performance on the Peabody Picture Vocabulary Test, Revised (PPVT-R; Dunn & Dunn, 1981) when the child was 36 months old. Time-varying covariates for the presence of the mother's husband or partner at home and maternal depression during childhood, measured with the CES-D, were included in all analyses. Table 1 reports the descriptive statistics for these control variables.

Statistical analyses

Growth curve analyses

Our primary analytic strategy was longitudinal growth-curve modeling using hierarchical linear models. In this approach, a Level-1 model is estimated that represents the individual change in EF performance across time and includes both fixed components and random components (intercept and slope) that are permitted to vary across individuals. Level-2 models are also estimated in which the variance in the intercept and slope parameters at Level-1 is predicted by time-invariant, person-level predictors. To ease interpretation, the value of time was centered on the age of the first assessment, such that the intercept represents performance at the youngest age of assessment. Fixed effects reflecting quadratic change were included in the models and retained if significant. Analyses were conducted in HLM6 (Raudenbush, Bryk & Congdon, 2004) using full maximum likelihood estimation. Two independent variables were examined at Level-2: early childhood income-to-needs and maternal education as predictors of both initial status and linear change. In addition, we examined the fixed effect, at Level-1, of income-to-needs representing change since early childhood (Singer & Willett, 2003). Level-2 variables were grand-mean centered. Estimates of fixed effects were obtained with robust standard errors.

We employed a step-wise procedure for each of the four outcomes of interest. First, we created an unconditional linear growth model to identify significant variance in both the intercept and slope at Level-1. Second, we added independent variables at Level-1 and at Level-2 for all random effects for which significant or trend-level ($p < .10$) variation existed, given the possibility of overestimation of p-values for random effect terms (Altham, 1984). Third, we added potential control variables individually to this basic model, and noted each variable which was significant at a trend level of $p < .10$ and for which the fit of the prediction model was improved (Singer & Willett, 2003). Fourth, we created a prediction model including all variables identified in step 3 and then removed non-significant ($p > .05$) control variables sequentially starting with the highest p-value, until only significant control variables remained. Fifth, once the final model was obtained for each outcome, we ran each model with time centered on the final age of assessment to examine the persistence of differences through third grade for working memory and fifth grade for planning efficiency.

Mediation analyses

Mediation analyses employed multilevel mediation, using a 2 → 2 → 1 approach, in which a Level-2, person-level variable mediates the effect of significant Level-2 independent variables on time-varying outcomes (Krull & MacKinnon, 2001; MacKinnon, 2008). Estimates of the $\hat{a}$ pathways, the relation between the independent variable and possible mediators, were obtained using ordinary least squares regression in PASW 18.0 (IBM, New York, NY). If both income-to-needs and maternal education were significant Level-2 predictors, estimates of the $\hat{a}$ pathways were obtained for both simultaneously in a single regression model. Estimates of the $\hat{b}$ and the $\hat{c}'$ pathways, representing the relation between the mediator and the outcome and the independent variable(s) and the outcome (with the mediator in the model) were obtained in HLM 6.08. The significance of the indirect pathway $\hat{a}\hat{b}$ was assessed by building 95% confidence intervals (CIs) in RMediation using the distribution of the product method (MacKinnon, 2008; Tofighi & MacKinnon, 2011).

To identify specific and independent mediation pathways, we first ran mediation models for each putative mediator individually and then employed a multiple mediation model with all mediators that were individually significant, to examine whether such pathways operate independently. This process then was repeated for adjusted mediators. By doing so, we were able to determine if (a) results were consistent using both raw and adjusted mediators, and (b) if there was a difference in the proportion of the effect mediated using raw or adjusted mediators, thus determining the importance of the shared variance across mediators.

Results

Sample characteristics

Sample characteristics for basic demographic information as well as mediators are illustrated in Table 1. Families had, on average, an early childhood income-to-needs ratio of 3.6 ($SD = 2.7$) ranging from 0.15 to 18.76, with an interquartile range of 1.9 to 4.6. Eighty-eight

(8.7%) families had an average early income-to-needs ratio of less than 1.0, or below the poverty line, while another 206 families (20.4%) had an income-to-needs ratio between 1.0 and 2.0. Mothers had an average of 14.5 years of education (SD = 2.4), and 74 (7.3%) had less than a high school education. Maternal education ranged from 7 to 21 years, with an interquartile range of 12 to 16.

Across the duration of the study, family income-to-needs increased over time ($F(3.25, 2394.49) = 51.12$, $p < .001$). However, the interquartile ranges for change scores in the income-to-needs ratio compared to early childhood income were −0.55 to 0.63, −0.53 to 1.07, −0.42 to 1.51, and −0.40 to 1.87 for 54 months and Grades 1, 3 and 5, respectively. Consequently, despite overall increases in family income-to-needs across the study, there was considerable heterogeneity, with many families experiencing decreases in income-to-needs.

Working memory

Growth curve analyses

As illustrated in Table 4, the effect of family income-to-needs on the intercept for working memory was significant and positive (B = 2.83 SE = 0.88, p = .002, r_{effect} = .10), with higher family income-to-needs predicting better performance at 54 months of age. Maternal education exhibited trend-level significance (B = 0.51, SE = 0.29, p = .08, r_{effect} = .06). With respect to predictors of developmental change, neither early family income-to-needs nor maternal education were significant predictors of slope (all $p > 0.5$). Change in family income was significant at the trend level (B = 0.89, SE = 0.53, p = .09, r_{effect} = .03). Effects of early income-to-needs (B = 2.2, SE = 0.8, $p < .01$, r_{effect} = .09) and maternal education (B = 0.57 SE = 0.24, p = .02, r_{effect} = .07) on the intercept were significant at 9.5 years old, as both higher family income-to-needs and maternal education predict better performance. Consequently, the effect of income-to-needs emerged early in childhood and persisted over time.

Mediation analysis

Mediation analyses focused on the effect of early childhood income-to-needs on the intercept, or performance at 54 months, and are summarized in Table 5. In single mediation models using adjusted mediators, the only significant, independent mediator was the early childhood home enrichment composite, $\hat{a}\hat{b}$= 0.37, 95% CI [0.18, 0.61], which partially mediated the effect of income-to-needs. The proportion of variance explained by the early childhood enrichment composite was 0.04.

In contrast, in single mediation models using unadjusted data for each mediator, infant/toddler home enrichment, $\hat{a}\hat{b}$= 0.74, 95% CI [0.20, 1.28], early childhood home enrichment, $\hat{a}\hat{b}$= 1.88, 95% CI [1.30, 2.49], infant/toddler maternal sensitivity, $\hat{a}\hat{b}$= 0.67, 95% CI [0.12, 1.23], and early childhood maternal sensitivity, $\hat{a}\hat{b}$= 0.87, 95% CI [0.38, 1.37], were significant mediators. The proportion of variance explained was 0.14, 0.29, 0.10, and 0.13, respectively, with all partially mediating the effect of income-to-needs. However, a multiple mediator model indicated that both early childhood home enrichment, $\hat{a}\hat{b}$= 1.74, 95% CI [1.10, 2.40], and early childhood maternal sensitivity, $\hat{a}\hat{b}$= 0.57, 95% CI [0.05, 1.11], significantly and fully mediated the association and

Table 4 *Multilevel models of executive function development: estimates of fixed (top) and random (bottom) effects*

	Working memory		Planning efficiency	
	Fixed effects			
Parameter	B	r_{effect}	B	r_{effect}
Initial status, π_{0i}				
Intercept	455.95***	1.00	12.31***	.78
Income-to-needs, early	2.83**	.10	0.93*	.07
Maternal education	0.51^	.06	.25*	.06
Gender			1.47***	.13
African-American	−4.24**	.10	−3.15***	.16
Hispanic / Latino	−5.48*	.08		
Maternal vocabulary	0.20***	.23		
Age, π_{1i}				
Intercept	12.48***	.73	4.05***	.45
Income-to-needs, early	−.013	.02	0.04	.01
Maternal education	0.01	.01	−0.01	.01
Hispanic / Latino	1.00*	.08		
Maternal vocabulary			0.01^	.05
Age-squared, π_{2i}	−0.84***	.23	−0.15**	.07
Income-to-needs, change relative to early π_{3i}	0.89^	.03	0.63*	.04
	Random effects			
	Estimate	SE	Estimate	SE
Level 1				
Within-person, σ_ε^2	61.41	3.02	32.15	1.61
Level 2				
Initial status, σ_0^2	206.11	12.21	15.47	3.18
Age, σ_1^2	6.8	0.72	0.21	0.24
Covariance, σ_{01}	−27.12	2.51	0.52	0.73
R_ε^2	.87		.63	
R_0^2	.17		.20	
R_1^2	.03		.20	
Deviance	21299.78		17051.71	

^ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$.

Table 5 *Mediation analysis of the effect of income-to-needs on working memory*

	Single mediator		Multiple mediator		Single mediator, adjusted	
Mediator	$\hat{a}\hat{b}$	Proportion mediated	$\hat{a}\hat{b}$	Proportion mediated	$\hat{a}\hat{b}$	Proportion mediated
Birthweight	−0.02	0.01			0.01	0.02
Gestational age	−0.05	−0.03			−0.06	−0.03
Maternal depression	0.22	0.05			0.04	0.01
Negative life events	−0.02	−0.02			−0.02	−0.02
Parent stress	0.00	0.00			0.02	0.00
Enrichment: Infant / Toddler	0.74*	0.14	0.01		−0.06	−0.02
Enrichment: Early childhood	1.88*	0.29	1.74*		0.37*	0.04
Maternal sensitivity: Infant/ Toddler	0.67*	0.10	0.13		−0.06	−0.01
Maternal sensitivity: Early childhood	0.87*	0.13	0.57*		0.07	0.01
Proportion mediated, multiple model				0.38°		

Note: Adjusted mediators control for the correlation of each mediator with the other mediators. $\hat{a}\hat{b}$ = estimate of the magnitude of the mediated effect.
*Mediation pathway significant, indicated by 95% confidence limits. ° Full mediation

yielded a higher estimate of the proportion of variance explained, 0.38, than in the model with the adjusted mediator.

Planning

Growth curve analyses

Early childhood family income-to-needs and the intercept for planning efficiency were significantly and positively related ($B = 0.93$, $SE = 0.43$, $p = .03$, $r_{effect} = .07$), such that higher family income-to-needs predicts better planning efficiency by first grade. The final model, including all covariates that met criteria for inclusion, is displayed in Table 4. Maternal education was also a significant, positive predictor of the intercept for planning efficiency ($B = 0.25$, $SE = 0.12$, $p = .04$, $r_{effect} = .06$). In addition, change in family income was independently significant ($B = 0.63$, $SE = 0.30$, $p = .03$, $r_{effect} = .04$), with decreases in income-to-needs at each time point, as compared to early childhood, predicting decreases in planning efficiency. With respect to developmental change, neither early family income-to-needs nor maternal education were significant predictors of slope (all $p \geq .69$). Effects on the intercept remained significant and in the same direction at fifth grade, as both higher early family income-to-needs ($B = 1.25$, $SE = 0.43$, $p = .004$, $r_{effect} = .09$) and maternal education ($B = 0.28$ $SE = 0.13$, $p = .03$, $r_{effect} = .07$) continued to predict better performance.

Mediation analysis

Mediation analyses focused on the effect of early childhood income-to-needs and maternal education on the intercept, and are summarized in Table 6.

Income-to-needs. In single mediation models using adjusted mediators, the only significant, partial mediator was early childhood home enrichment, $\hat{a}\hat{b}$= 0.05, 95% CI [0.002, 0.13]. The proportion of variance explained by early childhood home enrichment was 0.05. The indirect pathway from income-to-needs to planning efficiency via infant/toddler home enrichment was significant, $\hat{a}\hat{b}$= −0.10, 95% CI [−0.21, −0.02], but in the opposite direction, inconsistent with mediation. A multiple mediator model utilizing adjusted data that included early childhood home enrichment and maternal sensitivity (included due to its utility as a mediator of maternal education effects) also indicated that only early childhood enrichment, $\hat{a}\hat{b}$= 0.07, 95% CI [0.01, 0.15], was a significant mediator.

In contrast, in single mediation models using unadjusted data for each mediator, early childhood home enrichment, $\hat{a}\hat{b}$= 0.29, 95% CI [0.12, 0.49], infant/toddler maternal sensitivity, $\hat{a}\hat{b}$= 0.21, 95% CI [0.03, 0.41], and early childhood maternal sensitivity, $\hat{a}\hat{b}$= 0.34, 95% CI [0.19, 0.52], were significant, full mediators. The proportion of variance explained was 0.25, 0.16 and 0.29, respectively. A multiple mediator model indicated that early childhood home enrichment, $\hat{a}\hat{b}$= 0.22 95% CI [0.04, 0.41], and early childhood maternal sensitivity, $\hat{a}\hat{b}$= 0.30, 95% CI [0.14, 0.49], were significant mediators. The proportion of variance explained by this model was 0.47, and the effect of income-to-needs was fully mediated.

Maternal education. In single mediation models of maternal education and planning efficiency using adjusted mediators, early childhood home enrichment, $\hat{a}\hat{b}$ = 0.03, 95% CI [0.003, 0.06], and early childhood maternal sensitivity, $\hat{a}\hat{b}$ = 0.02, 95% CI [0.001, 0.05], fully mediated the association. The proportion of variance

Table 6 *Mediation analysis of the effect of income-to-needs and maternal education on planning efficiency*

	Single mediator		Multiple mediators		Single mediator, adjusted		Multiple mediators, adjusted	
Mediator	$\hat{a}\hat{b}$	Proportion mediated	$\hat{a}\hat{b}$	Proportion mediated	$\hat{a}\hat{b}$	Proportion mediated	$\hat{a}\hat{b}$	Proportion mediated
Income-to-needs								
Birthweight	0.00	−0.01			−0.01	−0.01		
Gestational age	0.01	0.01			0.00	0.01		
Maternal depression	0.06	0.08			0.00	0.01		
Negative life events	0.03	0.08			0.02	0.06		
Parent stress	0.01	0.01			0.00	0.00		
Enrichment: Infant / Toddler	−0.04	−0.03			−0.10*ˆ	−0.07		
Enrichment: Early childhood	0.29*	0.25°	0.22*		0.05*	0.05	0.07*	
Maternal sensitivity: Infant/ Toddler	0.21*	0.16°	0.02		−0.01	−0.01		
Maternal sensitivity: Early childhood	0.34*	0.29°	0.30*		0.02	0.03	0.02	
Proportion mediated, multiple model				0.47°				0.10°
Maternal education								
Birthweight	0.01	0.02			0.00	0.01		
Gestational age	0.00	0.00			0.00	0.00		
Maternal depression	0.02	0.05			0.00	0.01		
Negative life events	0.00	−0.01			0.02	0.01		
Parent stress	0.00	0.00			0.00	0.01		
Enrichment: Infant / Toddler	−0.01	−0.02			0.01	0.02		
Enrichment: Early childhood	0.09*	0.33°	0.06*		0.03*	0.10°	0.04*	
Maternal sensitivity: Infant/ Toddler	0.06*	0.23°	0.01		0.00	−0.01		
Maternal sensitivity: Early childhood	0.11*	0.43°	0.10*		0.02*	0.08°	0.02*	
Proportion mediated, multiple model				0.65°				0.19°

Note: Adjusted mediators control for the correlation of each mediator with the other mediators. $\hat{a}\hat{b}$ = estimate of the magnitude of the mediated effect. *Mediation pathway significant, indicated by 95% confidence limits. ° Full mediation ˆ Pathway is in opposite direction to main effect

explained was 0.10 and 0.08, respectively. In a multiple mediator model both the early childhood HOME, $\hat{a}\hat{b}$= 0.04 95% CI [0.01, 0.07], and early childhood maternal sensitivity, $\hat{a}\hat{b}$= 0.02 95% CI [0.001, 0.05], continued to fully mediate the association. The proportion of variance explained was 0.19.

In contrast, in single mediation models using unadjusted mediators, early childhood home enrichment, $\hat{a}\hat{b}$= 0.09, 95% CI [0.03, 0.14], infant/toddler maternal sensitivity, $\hat{a}\hat{b}$= 0.06, 95% CI [0.01, 0.11], and early childhood maternal sensitivity, $\hat{a}\hat{b}$= 0.11, 95% CI [0.06, 0.17], were significant mediators. The proportion of variance explained was 0.33, 0.23, and 0.43, respectively, with all fully mediating the effect. A multiple mediator model indicated that the early childhood HOME, $\hat{a}\hat{b}$= 0.06 95% CI [0.01, 0.12], and early childhood maternal sensitivity, $\hat{a}\hat{b}$= 0.10, 95% CI [0.05, 0.16], fully mediated the association. The proportion of variance explained was 0.65.

Discussion

Although EF has long been known to vary with childhood SES, two fundamental questions about this relation remain unanswered: the developmental course of the SES disparity over time and the aspects of childhood experience that mediate the relation. The foregoing analyses yield multiple new findings that address these questions.

First, two different indices of SES, income-to-needs and maternal education, independently and prospectively predicted performance on two tests of EF. Lower family income-to-needs predicted worse performance measured at the first available time point: at 54 months for working memory, and first grade for planning. Lower maternal education predicted worse performance by first grade for planning and third grade for working memory. These relations were independent of race and ethnicity, gender, maternal depression, whether the mother's husband or partner lived at home, and maternal verbal ability. Consequently the association between SES and EF has its roots early in childhood, suggesting that this epoch is particularly important for the development of individual differences in EF.

Second, these relations were stable over time. Early income-to-needs and maternal education did not influence later rates of developmental change in EF, and thus SES-related disparities did not increase or decrease over time. This is consistent with findings between the ages of 4 and 6 in early childhood (Hughes *et al.*, 2010) and in a longitudinal study from later childhood through adolescence (Hackman *et al.*, 2014). It also suggests that the relation between duration of poverty and working memory (Evans & Schamberg, 2009) may be due to the fact that more chronic poverty is likely to include earlier poverty. Consequently, lower-SES children develop EF at the same rate as their higher-SES counterparts; the SES-related performance disparity does not narrow by middle childhood. Any non-genetic causes of this association are therefore likely to be operating early in childhood, again highlighting the particular importance of this time period.

Third, above and beyond the effect of early childhood SES, later changes in family SES are associated with changes in EF. Decreases in family income-to-needs, relative to early childhood, predicted concomitant, time-varying decreases in planning ability with trend-level effects for working memory. This is consistent with intervention studies indicating that even small increases in income can influence achievement and psychopathology (Costello, Compton, Keeler & Angold, 2003; Duncan, Morris & Rodrigues, 2011). It is also consistent with data on EF under varying levels of life stress, indicating that the effects of stress on executive function may be reversible (Liston, McEwen & Casey, 2009). The current study finds that those at greatest risk for the worst outcomes are those children whose families have early and worsening poverty over time. In addition, despite the enduring association of early SES with EF performance, it also suggests that considerable plasticity remains in EF in later development.

Fourth, we were able to identify an aspect of childhood experience that partially mediates the SES disparity in EF consistently across the different EF measures: the quality of the early childhood home environment, which was a significant mediator of all SES–EF associations after adjusting for its correlation with other candidate mediators. This supports the family investment model (Conger & Donnellan, 2007). Maternal sensitivity during early childhood mediated the relation between maternal education and planning, lending partial support to the family stress model as well (Conger & Donnellan, 2007). The quality of the home environment and maternal sensitivity during infancy and toddlerhood, negative or stressful life events, birthweight, gestational age, postpartum maternal depression, or parent stress during infancy were not significant mediators with either adjusted mediators or with unadjusted data in multiple mediation models. Notably, this specific mediation pathway is consistent with earlier findings that aspects of the learning environment and parental scaffolding contribute to EF development (Bernier *et al.*, 2012, 2010; Bibok *et al.*, 2009; Clark *et al.*, 2013; A. Conway & Stifter, 2012; Hammond *et al.*, 2012; Hughes & Ensor, 2009) and that schooling impacts EF performance (Burrage, Ponitz, McCready, Shah, Sims, Jewkes & Morrison, 2008). In particular, these results converge to suggest that both the provision of a stimulating environment and the parent's own investment of time, guidance, and support in navigating that environment are of importance for the relation between SES and EF. However, shared variance among mediators also contributed to the SES–EF association. At present we cannot know what aspects of SES are responsible for this. For example, the shared variance may obscure the effect of specific pathways via a particular candidate mediator. However, it may also be that the covariance among mediators is itself critical, and cumulative risk or multiple stressor exposure may be the mechanism explaining a significant portion of the variance in this association (Evans & Kim, 2010).

Fifth, correlated candidate mediators must be taken into account when performing mediation analyses regarding SES and EF. Failing to adjust for the correlated nature of candidate mediators had a major effect on the results. Without adjustment, the quality of the home environment and maternal sensitivity in infancy/toddlerhood were significant individual mediators, while early childhood maternal sensitivity was a significant mediator of all SES–EF relations. Adjusting for the correlation among mediators eliminated the pathways through the home environment and maternal sensitivity in infancy/toddlerhood as well as through early childhood maternal sensitivity for all but the relation between maternal education and planning. Adjustment also significantly reduced the estimates of the magnitude of the mediation pathway for the home environment. Previous studies examined only one or a small set of candidate mediators without such adjustment (Blair *et al.*, 2011; Dilworth-Bart, Khurshid & Vandell, 2007; Evans & Schamberg, 2009; Sarsour *et al.*, 2011), likely explaining their mixed findings.

The present study examined nine primary candidate mediators; however, these candidate mediators do not represent all possible pathways. In particular, it remains possible that the effect of stress experienced directly by the child, with resultant effects on function of children's stress response systems, is an important pathway. The mediation analysis did include reports of stressful life events made by primary caregivers, including many events that can be conceptualized as direct stressors for children. Notably, such reports of stressful life events did not explain the association between SES and EF, suggesting that direct stressors on children that are observed by parents are unlikely to account for such associations. However, it may be that the direct effects of stress are carried by stressors that are not observable by parents or by differences in the function of stress response systems such as the hypothalamic-pituitary adrenal axis (e.g. Blair *et al.*, 2011). Consequently, although examination of nine primary candidate mediators renders the degree to which confounds are addressed a strength of this analysis, such alternative pathways cannot be entirely ruled out.

This result constrains causal models of the SES–EF association. Of course, correlational data cannot definitively answer questions about causality. However, this finding is inconsistent with certain other causal hypotheses, particularly genetic accounts of the SES–EF relation whereby families with innately lower EF drift downward in socioeconomic status. A genetic account of the SES disparity in EF is plausible, given the high estimates of EF heritability based on a twin study (Friedman, Miyake, Young, DeFries, Corley & Hewitt, 2008). However, the fact that change in later income-to-needs predicts change in EF cannot be explained by genetics. Although such change does not definitively indicate causality (Singer & Willett, 2003), it does provide increased support for this inference (Duckworth, Tsukayma & May, 2010). In addition, evidence in twin studies that parental cognitive stimulation influences children's cognitive performance via an environmental pathway (Tucker-Drob & Harden, 2012) supports a family investment pathway that is at least partly causal.

The SES differences in EF found in this paper are relevant for intervention design as well as policy. That early childhood SES has a lasting, consistent association with EF highlights the potential value of early intervention for low-SES families. That this effect is mediated by the quality of the home environment and by maternal sensitivity, to a lesser degree, suggests that these are reasonable candidate targets for intervention. However, the present results also indicate that prospects for effective intervention do not end with early childhood. Change in family income predicts change in EF, suggestive of potential plasticity in EF development, and it also highlights the potential effectiveness of intervening after children enter school, as has been shown with psychopathology and achievement (Costello *et al.*, 2003; Duncan *et al.*, 2011). Such interventions, both early in childhood and later in development, may include those designed to enhance executive function through training, which may be successful for some but not all children (Klingberg, 2010; Melby-Lervag & Hulme, 2013; Soderqvist, Nutley, Peyrard-Janvid, Matsson, Humphreys, Kere & Klingberg, 2012).

In summary, lower family income-to-needs and maternal education in early childhood predict worse performance on tasks of EF by 54 months that largely persist through middle to late childhood. No differences in developmental change were observed, but changes in family income predict concomitant changes in EF. Moreover, the quality of the early childhood home environment was a specific mediator of all SES–EF associations, even after controlling for other candidate mediators. As EF is an important predictor of educational success and socioemotional development, such SES-related disparities that are partially accounted for by the early childhood home environment are central targets for interventions and prevention programs.

Acknowledgements

Support for this research and preparation of this manuscript was provided by grants from the National Institute of Child Health and Human Development (R01 HD055689), National Institute of Mental Health (T32 MH018269) and the US National Institute on Drug Abuse (R01-DA14129). The content is solely the responsibility of the authors and does not necessarily represent the official views of the funding agencies. We would like to thank the families, staff and investigators of the NICHD Study of Early Child Care. We would also like to thank David Kraemer and Victor Schinazi for helpful discussion concerning the analysis and comments on the manuscript.

References

Aarnoudse-Moens, C.S.H., Weisglas-Kuperus, N., van Goudoever, J.B., & Oosterlaan, J. (2009). Meta-analysis of neurobehavioral outcomes in very preterm and/or very low birth weight children. *Pediatrics*, **124** (2), 717–728. doi:10.1542/peds.2008-2816

Abidin, R.R. (1983). *Parenting Stress Index Manual*. Charlottesville, VA: Pediatric Psychology Press.

Albert, D., & Steinberg, L. (2011). Age differences in strategic planning as indexed by the Tower of London. *Child Development*, **82** (5), 1501–1517.

Alloway, T.P., & Alloway, R.G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology*, **106** (1), 20–29.

Alloway, T.P., Gathercole, S.E., Adams, A.-M., Willis, C., Eaglen, R., & Lamont, E. (2005). Working memory and phonological awareness as predictors of progress towards early learning goals at school entry. *British Journal of Developmental Psychology*, **23** (3), 417–426.

Altham, P.M.E. (1984). Improving the precision of estimation by fitting a model. *Journal of the Royal Statistical Society, Series B*, **46**, 118–119.

Ardila, A., Rosselli, M., Matute, E., & Guajardo, S. (2005). The influence of the parents' educational level on the development of executive functions. *Developmental Neuropsychology*, **28** (1), 539–560.

Arnsten, A.F.T. (2009). Stress signalling pathways that impair prefrontal cortex structure and function. *Nature Reviews Neuroscience*, **10** (6), 410–422.

Azjen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, **50**, 179–211.

Baddeley, A. (2003). Working memory: looking back and looking forward. *Nature Reviews Neuroscience*, **4** (10), 829–839.

Baron, R.M., & Kenny, D.A. (1986). The moderator–mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology*, **51**, 1173–1182.

Beck, C.T. (2001). Predictors of postpartum depression: an update. *Nursing Research*, **50** (5), 275–285.

Bernier, A., Carlson, S.M., Deschenes, M., & Matte-Gagne, C. (2012). Social factors in the development of early executive functioning: a closer look at the caregiving environment. *Developmental Science*, **15** (1), 12–24.

Bernier, A., Carlson, S.M., & Whipple, N. (2010). From external regulation to self-regulation: early parenting precursors of young children's executive functioning. *Child Development*, **81** (1), 326–339.

Best, J.R., & Miller, P.H. (2010). A developmental perspective on executive function. *Child Development*, **81** (6), 1641–1660.

Bibok, M.B., Carpendale, J.I.M., & Muller, U. (2009). Parent scaffolding and the development of executive function. *New Directions in Child and Adolescent Development*, **123**, 17–34.

Blair, C. (2013). Executive functions in the classroom. In J.B. Morton (Ed.), *Encyclopedia on Early Childhood Development [online]*. Montreal, Quebec: Centre of Excellence for Early Childhood Development and Strategic Knowledge Cluster on Early Child Development.

Blair, C., Granger, D.A., Willoughby, M., Mills-Koonce, R., Cox, M., Greenberg, M.T., Kivlighan, K.T., Fortunato, C.K., & the FLP Investigators (2011). Salivary cortisol mediates effects of poverty and parenting on executive functions in early childhood. *Child Development*, **82** (6), 1970–1984.

Blume, A.W., & Marlatt, G.A. (2009). The role of executive cognitive functions in changing substance use: what we know and what we need to know. *Annals of Behavioral Medicine*, **37** (2), 117–125.

Borys, S.V., Spitz, H.H., & Dorans, B.A. (1982). Tower of Hanoi performance of retarded young adults and nonretarded children as a function of solution length and goal state. *Journal of Experimental Child Psychology*, **33** (1), 87–110.

Bradley, R.H., & Corwyn, R.F. (2002). Socioeconomic status and child development. *Annual Review of Psychology*, **53**, 371–399.

Brooks-Gunn, J., & Duncan, G.J. (1997). The effects of poverty on children. *The Future of Children*, **7** (2), 55–71.

Bull, R., Espy, K.A., & Wiebe, S.A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology*, **33** (3), 205–228.

Burrage, M.S., Ponitz, C.C., McCready, E.A., Shah, P., Sims, B.C., Jewkes, A.M., & Morrison, F.J. (2008). Age- and schooling-related effects on executive functions in young children: a natural experiment. *Child Neuropsychology*, **14** (6), 510–524.

Caldwell, B.M., & Bradley, R.H. (1984). *Home Observation for Measurement of the Environment*. Little Rock, AR: University of Arkansas at Little Rock.

Clark, C.A.C., Pritchard, V.E., & Woodward, L.J. (2010). Preschool executive functioning predicts early mathematics achievement. *Developmental Psychology*, **46** (4), 1176–1191.

Clark, C.A.C., Sheffield, T.D., Chevalier, N., Nelson, J.M., Wiebe, S.A., & Espy, K.A. (2013). Charting longitudinal trajectories of executive control with the shape school. *Developmental Psychology*, **49** (8), 1481–1493. doi:10.1037/a0030578

Conger, R.D., & Donnellan, M.B. (2007). An interactionist perspective on the socioeconomic context of human development. *Annual Review of Psychology*, **58**, 175–199.

Conway, A., & Stifter, C.A. (2012). Longitudinal antecedents of executive function in preschoolers. *Child Development*, **83** (3), 1022–1036.

Conway, A.R.A., Kane, M.J., & Engle, R.W. (2003). Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences*, **7** (12), 547–552.

Costello, E.J., Compton, S.N., Keeler, G., & Angold, A. (2003). Relationships between poverty and psychopathology: a natural experiment. *Journal of the American Medical Association*, **290** (15), 2023–2029.

Crook, S.R., & Evans, G.W. (2014). The role of planning skills in the income–achievement gap. *Child Development*, **85** (2), 405–411.

D'Angiulli, A., Herdman, A., Stapells, D., & Hertzman, C. (2008). Children's event-related potentials of auditory selective attention vary with their socioeconomic status. *Neuropsychology*, **22** (3), 293–300.

Daneman, M., & Merikle, P.M. (1996). Working memory and language comprehension: a meta-analysis. *Psychonomic Bulletin & Review*, **3** (4), 422–433.

Dilworth-Bart, J., Khurshid, A., & Vandell, D. (2007). Do maternal stress and home environment mediate the relation between early income-to-need and 54-month attention? *Infant and Child Development*, **16**, 525–552.

Duckworth, A.L., Tsukayma, E., & May, H. (2010). Establishing causality using longitudinal hierarchical linear modeling: an illustration predicting achievement from self-control. *Social Psychological and Personality Science*, **1** (4), 311–317.

Duncan, G.J., Morris, P.A., & Rodrigues, C. (2011). Does money really matter? Estimating impacts of family income on young children's achievement with data from random-assignment experiments. *Developmental Psychology*, **47** (5), 1263–1279.

Dunn, L.M., & Dunn, L.M. (1981). *Peabody Picture Vocabulary Test – Revised manual for Forms L and M*. Circle Pines, MN: American Guidance Service.

Eigsti, I.-M., Zayas, V., Mischel, W., Shoda, Y., Ayduk, O., Dadlani, M.B., Davidson, M.C., Aber, J.L., & Casey, B.J. (2006). Predicting cognitive control from preschool to late adolescence and young adulthood. *Psychological Science*, **17** (6), 478–484.

Engel, P.M.J., Santos, F.H., & Gathercole, S.E. (2008). Are working memory measures free of socioeconomic influence? *Journal of Speech, Language, and Hearing Research*, **51** (6), 1580–1587. doi:10.1044/1092-4388(2008/07-0210

Espy, K.A., Stalets, M.M., McDiarmid, M.M., Senn, T.E., Cwik, M.F., & Hamby, A. (2002). Executive functions in preschool children born preterm: application of cognitive neuroscience paradigms. *Child Neuropsychology*, **8** (2), 83–92.

Evans, G.W. (2004). The environment of childhood poverty. *American Psychologist*, **59** (2), 77–92.

Evans, G.W., & Kim, P. (2010). Multiple risk exposure as a potential explanatory mechanism for the socioeconomic status–health gradient. *Annals of the New York Academy of Sciences*, **1186** (1), 174–189.

Evans, G.W., & Kim, P. (2013). Childhood poverty, chronic stress, self-regulation, and coping. *Child Development Perspectives*, **7** (1), 43–48.

Evans, G.W., & Schamberg, M.A. (2009). Childhood poverty, chronic stress, and adult working memory. *Proceedings of the National Academy of Sciences, USA*, **106** (16), 6545–6549. doi:10.1073/pnas.0811910106

Farah, M.J., Shera, D.M., Savage, J.H., Betancourt, L., Giannetta, J.M., Brodsky, N.L., Malmud, E.K., & Hurt, H. (2006). Childhood poverty: specific associations with neurocognitive development. *Brain Research*, **1110** (1), 166–174.

Friedman, N.P., Miyake, A., Young, S.E., DeFries, J.C., Corley, R.P., & Hewitt, J.K. (2008). Individual differences in executive functions are almost entirely genetic in origin. *Journal of Experimental Psychology: General*, **137** (2), 201–225.

Gogtay, N., Giedd, J.N., Lusk, L., Hayashi, K.M., Greenstein, D., Vaituzis, A.C., Nugent, T.F., III, Herman, D.H., Clasen, L.S., Toga, A.W., Rapoport, J.L., & Thompson, P.M. (2004). Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National Academy of Sciences of the United States of America*, **101** (21), 8174–8179.

Grace, S.L., Evindar, A., & Stewart, D.E. (2003). The effect of postpartum depression on child cognitive development and behavior: a review and critical analysis of the literature. *Archives of Women's Mental Health*, **6** (4), 263–274.

Hackman, D.A., Betancourt, L.M., Gallop, R., Romer, D., Brodsky, N.L., Hurt, H., & Farah, M.J. (2014). Mapping the trajectory of socioeconomic disparity in working memory: parental and neighborhood factors. *Child Development*, **85** (4), 1433–1445. doi:10.1111/cdev.12242

Hackman, D.A., & Farah, M.J. (2009). Socioeconomic status and the developing brain. *Trends in Cognitive Sciences*, **13** (2), 65–73.

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.

Hammond, S.I., Muller, U., Carpendale, J.I.M., Bibok, M.B., & Lieberman-Finestone, D.P. (2012). The effects of parental scaffolding on preschoolers' executive function. *Developmental Psychology*, **48** (1), 271–281.

Hughes, C., & Ensor, R. (2009). How do families help or hinder the emergence of early executive function? *New Directions in Child and Adolescent Development*, **123**, 35–50.

Hughes, C., Ensor, R., Wilson, A., & Graham, A. (2010). Tracking executive function across the transition to school: a latent variable approach. *Developmental Neuropsychology*, **35** (1), 20–36.

Hughes, C., Roman, G., Hart, M.J., & Ensor, R. (2013). Does maternal depression predict young children's executive function? A 4-year longitudinal study. *Journal of Child Psychology and Psychiatry*, **54** (2), 169–177. doi:10.1111/jcpp.12014

Huizinga, M., Dolan, C.V., & van der Molen, M.W. (2006). Age-related change in executive function: developmental trends and a latent variable analysis. *Neuropsychologia*, **44** (11), 2017–2036.

Jaffee, S.R., & Gallop, R. (2007). Social, emotional, and academic competence among children who have had contact with child protective services: prevalence and stability estimates. *Journal of the American Academy of Child and Adolescent Psychiatry*, **46** (6), 757–765.

Jednorog, K., Altarelli, I., Monzalvo, K., Fluss, J., Dubois, J., Billard, C., Dehaene-Lambertz, G., & Ramus, F. (2012). The influence of socioeconomic status on children's brain structure. *PLoS ONE*, **7** (8), e42486. doi:10.1371/journal.pone.0042486

Kishiyama, M.M., Boyce, W.T., Jimenez, A.M., Perry, L.M., & Knight, R.T. (2009). Socioeconomic disparities affect prefrontal function in children. *Journal of Cognitive Neuroscience*, **21** (6), 1106–1115. doi:10.1162/jocn.2009.21101

Klingberg, T. (2010). Training and plasticity of working memory. *Trends in Cognitive Sciences*, **14** (7), 317–324.

Krull, J.L., & MacKinnon, D.P. (2001). Multilevel modeling of individual and group level mediated effects. *Multivariate Behavioral Research*, **36** (2), 249–277.

Landry, S.H., Miller-Loncar, C.L., Smith, K.E., & Swank, P.R. (2002). The role of early parenting in children's development of executive processes. *Developmental Neuropsychology*, **21** (1), 15–41.

Lipina, S.J., Martelli, M.I., Vuelta, B., & Colombo, J.A. (2005). Performance on the A-not-B task of Argentinean infants from unsatisfied and satisfied basic needs homes. *Interamerican Journal of Psychology*, **39** (1), 49–60.

Lipina, S.J., Martelli, M.I., Vuelta, B.L., Injoque-Ricle, I., & Colombo, J.A. (2004). Pobreza y desempeno ejecutivo en alumnos preescolares de la ciudad de Buenos Aires (Republica Argentina). / Poverty and executive performance in preschool pupils from Buenos Aires city (Republica Argentina). *Interdisciplinaria*, **21** (2), 153–193.

Liston, C., McEwen, B.S., & Casey, B.J. (2009). Psychosocial stress reversibly disrupts prefrontal processing and attentional control. *Proceedings of the National Academy of Sciences of the United States of America*, **106** (3), 912–917.

Luu, T.M., Ment, L., Allan, W., Schneider, K., & Vohr, B.R. (2011). Executive and memory function in adolescents born very preterm. *Pediatrics*, **127** (3), e639–e646.

MacKinnon, D.P. (2008). *Introduction to statistical mediation analysis*. New York: Lawrence Erlbaum Associates.

McLoyd, V.C. (1998). Socioeconomic disadvantage and child development. *American Psychologist*, **53** (2), 185–204.

Melby-Lervag, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology*, **49** (2), 270–291. doi:10.1037/a0028228

Mezzacappa, E. (2004). Alerting, orienting, and executive attention: developmental properties and sociodemographic correlates in an epidemiological sample of young, urban children. *Child Development*, **75** (5), 1373–1386.

Miller, E.K., & Cohen, J.D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, **24**, 167–202.

Miller, P., Votruba-Drzal, E.P., & Setodji, C.M. (2013). Family income and early achievement across the urban–rural continuum. *Developmental Psychology*, **49** (8), 1452–1465. doi:10.1037/a0030244

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** (1), 49–100.

NICHD Early Child Care Research Network (1999). Child care and mother–child interaction in the first three years of life. *Developmental Psychology*, **35** (6), 1399–1413.

NICHD Early Child Care Research Network (2005). Duration and developmental timing of poverty and children’s cognitive and social development from birth through third grade. *Child Development*, **76** (4), 795–810.

Noble, K.G., Houston, S.M., Kan, E., & Sowell, E.R. (2012). Neural correlates of socioeconomic status in the developing human brain. *Developmental Science*, **15** (4), 516–527.

Noble, K.G., McCandliss, B.D., & Farah, M.J. (2007). Socioeconomic gradients predict individual differences in neurocognitive abilities. *Developmental Science*, **10** (4), 464–480.

Noble, K.G., Norman, M.F., & Farah, M.J. (2005). Neurocognitive correlates of socioeconomic status in kindergarten children. *Developmental Science*, **8** (1), 74–87.

Ochsner, K.N., & Gross, J.J. (2008). Cognitive emotion regulation: insights from social cognitive and affective neuroscience. *Current Directions in Psychological Science*, **17** (2), 153–158.

Pentz, M.A., & Riggs, N.R. (2013). Longitudinal relationships of executive cognitive function and parent influence to child substance use and physical activity. *Prevention Science*, **14** (3), 229–237.

Radloff, L.S. (1977). The CES-D scale: a self-report depression scale for research in the general population. *Applied Psychological Measurement*, **1** (3), 385–401.

Raizada, R.D.S., & Kishiyama, M.M. (2010). Effects of socioeconomic status on brain development, and how cognitive neuroscience may contribute to levelling the playing field. *Frontiers in Human Neuroscience*, **4**, doi:10.3389/neuro.09.003.2010

Raudenbush, S.W., Bryk, A.S., & Congdon, R.T. (2004). HLM 6 for Windows (Version 6.08). Lincolnwood, IL: Scientific Software International, Inc.

Raver, C.C., Blair, C., & Willoughby, M. (2013). Poverty as a predictor of 4-year-olds’ executive function: new perspectives on models of differential susceptibility. *Developmental Psychology*, **49** (2), 292–304.

Rhoades, B.L., Greenberg, M.T., Lanza, S.T., & Blair, C. (2011). Demographic and familial predictors of early executive function development: contribution of a person-centered perspective. *Journal of Experimental Child Psychology*, **108** (3), 638–662.

Riggs, N.R., Chou, C.-P., Spruijt-Metz, D., & Pentz, M.A. (2010). Executive cognitive function as a correlate and predictor of child food intake and physical activity. *Child Neuropsychology*, **16**, 279–292.

Robinson, G.K. (1991). That BLUP is a good thing: the estimation of random effects. *Statistical Science*, **6** (1), 15–51.

Sarason, I.G., Johnson, J.H., & Siegel, J.M. (1978). Assessing the impact of life changes: development of the Life Experiences Survey. *Journal of Consulting and Clinical Psychology*, **36** (5), 932–946.

Sarsour, K., Sheridan, M., Jutte, D., Nuru-Jeter, A., Hinsh, 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** (1), 120–132.

Shaw, P., Kabani, N.J., Lerch, J.P., Eckstrand, K., Lenroot, R., Gogtay, N., Greenstein, D., Clasen, L., Evans, A., Rapoport, J.L., Giedd, J.N., & Wise, S.P. (2008). Neurodevelopmental trajectories of the human cerebral cortex. *Journal of Neuroscience*, **28** (14), 3586–94.

Sheridan, M.A., Sarsour, K., Jutte, D., D’Esposito, M., & Boyce, W.T. (2012). The impact of social disparity on prefrontal function in childhood. *PLoS One*, **7** (4), e35744.

Shonkoff, J.P., Boyce, W.T., & McEwen, B.S. (2009). Neuroscience, molecular biology, and the childhood roots of health disparities: building a new framework for health promotion and disease prevention. *Journal of the American Medical Association*, **301** (21), 2252–2259. doi:10.1001/jama.2009.754

Singer, J.D., & Willett, J.B. (2003). *Applied longitudinal data analysis: Modeling change and event occurrence*. New York: Oxford University Press.

Sirin, S.R. (2005). Socioeconomic status and academic achievement: a meta-analytic review of research. *Review of Educational Research*, **75** (3), 417–453.

Snyder, H.R. (2013). Major depressive disorder is associated with broad impairments on neuropsychological measures of executive function: a meta-analysis and review. *Psychological Bulletin*, **139** (1), 81–132.

Soderqvist, S., Nutley, S.B., Peyrard-Janvid, M., Matsson, H., Humphreys, K., Kere, J., & Klingberg, T. (2012). Dopamine, working memory, and training induced plasticity: implications

for developmental research. *Developmental Psychology*, **48** (3), 836–843.
St Clair-Thompson, H.L., & Gathercole, S.E. (2006). Executive functions and achievements in school: shifting, updating, inhibition, and working memory. *Quarterly Journal of Experimental Psychology*, **59** (4), 745–759.
Stevens, C., Lauinger, B., & Neville, H. (2009). Differences in the neural mechanisms of selective attention in children from different socioeconomic backgrounds: an event-related brain potential study. *Developmental Science*, **12** (4), 634–646.
Tofighi, D., & MacKinnon, D.P. (2011). RMediation: an R package for mediation analysis confidence intervals. *Behavior Research Methods*, **43** (3), 692–700. doi:10.3758/s13428-011-0076-x
Tucker-Drob, E.M., & Harden, K.P. (2012). Early childhood cognitive development and parental cognitive stimulation: evidence for reciprocal gene–environment transactions. *Developmental Science*, **15** (2), 250–259.
Ursache, A., Blair, C., & Raver, C.C. (2012). The promotion of self-regulation as a means of enhancing school readiness and early achievement in children at risk for school failure. *Child Development Perspectives*, **6** (2), 122–128.
Welsh, M.C. (1991). Rule-guided behavior and self-monitoring on the Tower of Hanoi disk-transfer task. *Cognitive Development*, **6** (1), 59–76.
Welsh, M.C., Pennington, B.F., Ozonoff, S., Rouse, B., & McCabe, E.R. (1990). Neuropsychology of early-treated phenylketonuria: specific executive function deficits. *Child Development*, **61** (6), 1697–1713.
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** (2), 575–587.
Wiebe, S.A., Sheffield, T., Nelson, J.M., Clark, C.A.C., Chevalier, N., & Espy, K.A. (2011). The structure of executive function in 3-year-olds. *Journal of Experimental Child Psychology*, **108** (3), 436–452.
Wong, C.L., & Mullan, B.A. (2009). Predicting breakfast consumption: an application of the theory of planned behaviour and the investigation of past behaviour and executive function. *British Journal of Health Psychology*, **14**, 489–504.
Woodcock, R.W. (1990). Theoretical foundations of the WJ-R measures of cognitive ability. *Journal of Psychoeducational Assessment*, **8** (3), 231–258.
Woodcock, R.W., & Johnson, M.B. (1989). *Woodcock-Johnson Psychoeducational Battery – Revised*. Allen, TX: DLM.
Zelazo, P.D., Carlson, S.M., & Kesek, A. (2008). Development of executive function in childhood. In C.A. Nelson & M. Luciana (Eds.), *Handbook of developmental cognitive neuroscience* (2nd edn., pp. 553–574). Cambridge, MA: MIT Press.

Received: 13 January 2013
Accepted: 31 July 2014