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Cognitive Stimulation as a Mechanism Linking Socioeconomic Status With Executive Function: A Longitudinal Investigation

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Executive functions (EF), including working memory, inhibition, and cognitive flexibility, vary as a function of socioeconomic status (SES), with children from economically disadvantaged backgrounds having poorer performance than their higher SES peers. Using observational methods, we investigated cognitive stimulation in the home as a mechanism linking SES with EF. In a sample of 101 children aged 60–75 months, cognitive stimulation fully mediated SES-related differences in EF. Critically, cognitive stimulation was positively associated with the development of inhibition and cognitive flexibility across an 18-month follow-up period. Furthermore, EF at T1 explained SES-related differences in academic achievement at T2. Early cognitive stimulation—a modifiable factor—may be a desirable target for interventions designed to ameliorate SES-related differences in cognitive development and academic achievement.

Executive functions (EF), including working memory, inhibitory control, and cognitive flexibility, are a set of cognitive skills involved in goal-directed behavior that are critical for adaptive functioning and academic success (Blair & Razza, 2007; Samuels, Tournaki, Blackman, & Zilinski, 2016). Children's EF ability varies as a function of socioeconomic status (SES), such that children from families with greater income and parental education perform better on EF tasks than children from lower-SES families (Dilworth-Bart, 2012; Hackman & Farah, 2009; Lawson, Hook, & Farah, 2018; Noble, McCandliss, & Farah, 2007; Noble, Norman, & Farah, 2005; Rosen, Sheridan, Sambrook, Meltzoff, & McLaughlin, 2018). SES-related disparities in academic achievement appear to be explained, at least in part, by these differences in EF (Finn et al., 2016; Rosen et al., 2018). Although considerable research has been dedicated to understanding this association, the underlying mechanisms explaining why SES is related to EF remain poorly understood. This study sought to evaluate whether the amount of cognitive stimulation in the home environment—measured using observational methods—is a mechanism accounting for SES-related differences in EF performance.

Prior research has observed a positive association between family SES and EF ability in youth, such that children raised by more highly educated parents and in families with greater income perform

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better on tests of working memory, inhibitory control, and cognitive flexibility than children raised in lower-SES families (Farah et al., 2006). The positive association between SES and EF is present in early childhood (Clearfield & Niman, 2012; Lipina, Martelli, Vuelta, & Colombo, 2005) and the gap neither widens nor narrows across development (Hackman, Gallop, Evans, & Farah, 2015). While some studies have found that EF does not vary as a function of SES (e.g., Engel, Santos, & Gathercole, 2008; Wiebe, Espy, & Charak, 2008), a recent meta-analysis that included data from thousands of children aged 2 to 18 years found a small-to-medium association between SES and EF and a stronger association among studies with multiple measures of EF (Lawson et al., 2018).

Despite evidence for an association between SES and EF, the mechanisms that explain why SES is related to EF remain poorly understood. In particular, the features of the early environment that vary as a function of SES and, in turn, may shape individual differences in EF, are largely unknown. Identifying the specific aspects of early environmental experience that explain the association between SES and EF is critical to developing effective early interventions to close this gap. A variety of potential environmental mechanisms linking SES in childhood and EF abilities have been proposed. These include: SES-related differences in parenting and interactions with caregivers, environmental predictability, exposure to toxins, poor nutrition, exposure to violence, and stress (Hackman & Farah, 2009; Hackman, Farah, & Meaney, 2010; Johnson, Riis, & Noble, 2016). Many mechanistic models explaining SES-related disparities in EF have focused on aspects of early experience, such as environmental enrichment, parental scaffolding of child learning, parental warmth, and language exposure (Carlson, 2009; Hackman et al., 2010; Lengua et al., 2014; Sheridan & McLaughlin, 2014; Sheridan & McLaughlin, 2016). We have recently proposed an integrated mechanistic model in which cognitive stimulation in the home environment—including parental involvement in learning, environmental complexity, and language quality and quantity—is a critical link explaining SES-related differences in EF (Rosen, Amso, & McLaughlin, 2019). Specifically, this model argues that interaction with caregivers early in development, coupled with an environment rich with complex sensory stimuli, plays a central role in the development of EF. In this model, cognitive stimulation encompasses four domains of early experience, including access to learning materials, caregiver involvement in learning, variety of experiences, and the quantity and quality of linguistic experience. This model proposes that cognitive stimulation is critical for EF development because caregivers guide attention and promote associative learning through language and other forms of social interaction that highlight features of the environment that require children to sustain and regulate attention and to resolve conflict between stimuli with overlapping features as they build semantic representations of different stimulus types (Rosen et al., 2019). These interactions provide critical scaffolding for the development of the prefrontal cortex and EF. Here, we directly test the hypothesis that cognitive stimulation is a mechanism explaining the association between SES and EF—including working memory, inhibition, and cognitive flexibility.

To be a plausible environmental mechanism linking SES with EF, cognitive stimulation must vary with SES. Indeed, prior research has found that children raised in lower SES-environments are exposed to lower levels of cognitive stimulation (Bradley & Corwyn, 2002; Bradley, Corwyn, McAdoo, & Garcia Coll, 2001; Hackman et al., 2015; Hart & Risley, 1995; Lengua, Honorado, & Bush, 2007; Lengua et al., 2014). In pioneering work using observations of the home environment, Bradley and Corwyn (2002) found that children from low-SES backgrounds had reduced access to enriching experiences, access to educational materials including books, and more limited parental involvement in learning such as teaching children to read (possibly due to time demands or parental education level). Other studies that have relied on parental reports have also found that parental education and family income are positively associated with the presence of cognitively stimulating materials and experiences (e.g., presence of books in the house), the degree of caregiver involvement in children's learning, and access to enriching experiences outside of the home (Christensen, Schieve, Devine, & Drews-Botsch, 2014; Hackman et al., 2015; Rosen et al., 2018).

The quantity and quality of linguistic experiences are another critical and well-studied aspect of cognitive stimulation that varies as a function of SES. In an early study, Hart and Risley found that that children in lower SES households were exposed to significantly fewer words than their higher SES counterparts (Hart & Risley, 1995). While this study was small, recent work has replicated the finding that SES is associated with the quantity of language exposure in children in larger samples and using technological advancements to more accurately track language exposure in the home (Fernald, Marchman, & Weisleder, 2013; Gilkerson et al., 2017). Furthermore, language quality also varies as a function of SES, such that higher SES parents use greater variety of words and more complex syntactical structure (Rowe, 2012). These specific, measurable differences in language exposure have in turn been associated with disparities in child language ability and vocabulary (Fernald et al., 2013; Ramírez-Esparza, García-Sierra, & Kuhl, 2014; Romeo et al., 2018). A recent study also found that maternal language complexity and vocabulary diversity measured in early childhood in the laboratory were associated with child EF later in development (Daneri, Blair, & Kuhn, 2018). Maternal language was associated with child vocabulary, which in turn mediated the association between maternal language and child EF. Taken together, the above studies highlight that children reared in lower SES environments tend to experience lower levels of cognitive stimulation in the home including access to learning materials, caregiver involvement in learning, access to enriching experiences, as well as reduced quantity and quality of linguistic experiences.

Three studies have directly tested whether SES-related differences in EF are explained by differences in cognitive stimulation. One study investigated the role of cognitive stimulation in EF ability in 8–12 year olds and found significant associations of access to learning materials and enrichment activities with EF and that enrichment activities mediated the association of SES with working memory and inhibition (Sarsour et al., 2011). A recent study in children aged 7–17 used parent report of enrichment activities and found that variation in cognitive stimulation and enrichment predicts working memory performance even at the high end of the SES distribution and mediates SES-related differences in working memory performance (Amso, Salhi, & Badre, 2018). However, the cross-sectional nature of these studies and the focus on older children make it difficult to determine whether cognitive stimulation plays a role in the link between SES and the *development* of EF over time. Indeed, EF disparities as a function of SES emerge quite early in development (Clearfield & Niman, 2012; Lipina et al., 2005). The only longitudinal study examining this question relied on parent-report to assess how aspects of the home environment might explain SES-related differences in EF along with a wide range of other potential mediators (Hackman et al., 2015). That study found that enrichment—a composite score that included access to learning materials, variety of experiences, and parental involvement in learning measured repeatedly across infancy and early childhood from 6 to 54 months—mediated the association between SES and both working memory and planning at 54 months, whereas other mechanisms (parental stress, negative life events, maternal depression, and birth weight), did not explain this association. While this study provides support for the idea that SES-related differences in EF can be explained, at least in part, by cognitive stimulation, assessments relied on parent-report of cognitive stimulation rather than in-home observations, used a limited set of EF measures, and did not examine EF growth over time. Here, we examine the role of cognitive stimulation in the home environment, assessed using observational methods, as a potential mechanism underlying the longitudinal association between SES and the development of EF abilities across the domains of working memory, inhibition, and cognitive flexibility.

The present study investigated the hypothesis that cognitive stimulation—including access to learning materials, parental involvement in learning, and language exposure—is a mechanism explaining the association between SES and EF. We assessed cognitive stimulation in the homes of 60- to 75-month-old children from a wide range of SES backgrounds using observational and structured interview metrics to quantify learning materials, caregiver involvement in learning, and variety of experiences, as well as a naturalistic assessment of language quantity and quality in the home. Children performed tasks to test the three major domains of EF: working memory, inhibition, and cognitive flexibility (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001) which are particularly important for school readiness and academic achievement (Blair, 2002; Coldren, 2013; Finn et al., 2016). One to 2-years later, children came into the laboratory and performed the same EF tasks as well as tests of academic achievement. We hypothesized that cognitive stimulation would be a mechanism explaining SES-related differences in EF concurrently as well as account for growth in EF over time and that SES-related differences in academic achievement would be explained by EF. Children growing up in low-SES environments often experience other adverse environmental experiences, including exposure to violence and even maltreatment (McLaughlin et al., 2012). Some have argued that exposure to violence may impact the development of EF (e.g., Hanson et al., 2010). Recent conceptual models have argued that experiences of threat (e.g., violence) and experiences of deprivation (e.g., an absence of cognitive stimulation) may have distinct impacts on cognitive and neural development and that controlling for co-occurring exposures is critical for isolating the effects of distinct types of environmental experience (McLaughlin, Sheridan, & Lambert, 2014; Sheridan & McLaughlin, 2014). To ensure that our findings reflect SES differences that are not explained by exposure to other forms of adversity, all analyses controlled for children's exposure to violence.

Method

Participants

A sample of 101 youths aged 60–75 months (M_{age} = 5.55 ± 0.37, 51 females) and their parents were participated in the study between February 2016 and September 2017. Families were recruited from the Seattle area via fliers posted at preschools, day cares, clinics, and from the general community. To ensure SES-related diversity, recruitment efforts focused on neighborhoods with wide variability in SES composition. The race and ethnicity of the families closely matched the demographics of the greater Seattle area (67.3% White, 14.8% Black, 2.9% American Indian or Alaska Native, 12.8% Asian, 0.9% Native Hawaiian or Pacific Islander, 0.9% Other; 8.9% Hispanic or Latino). The Institutional Review Board at the University of Washington approved all procedures. Participants were compensated and written informed consent was obtained from legal guardians. Youths provided verbal assent. Two female participants were excluded from all analyses due to having scores of verbal intelligence as assessed by the Peabody Picture Vocabulary Test (Dunn & Dunn, 2007) two standard deviations below the mean, which was an exclusion criteria for participation.

Socioeconomic Status

SES was assessed using two measures: the income-to-needs ratio and maximum parental education. The income-to-needs ratio captures the amount of annual income that a family earns relative to the federal poverty line for a family of that size. Parents reported annual income in 10 bins, and the median of the income bins was used except for the lowest and highest bins, which were assigned \$5,000 and \$200,000, respectively. Income-to-needs ratio was calculated by dividing the total household income by the 2016 U.S. census-defined poverty line for a family of that size, with a value less than one indicating income below the poverty line. Median income-to-needs was 4.49 with 8% of participants (income to needs < 1) were living in poverty and 23% of participants living at less than twice the poverty line. Income-to-needs is based on the federal poverty line and does not account for regional variation in cost of living. In the greater Seattle area, where data were collected, a 2017 study found that a family of four requires an income of approximately \$75,000 per year in order afford basic needs (i.e., food, housing, transportation, health care, and child care; Pearce, 2017). A family of three requires approximately \$70,000 per year and a family of two requires approximately \$57,000 per year. According to this standard, nearly half of our sample (48.5%) is below or near the self-sufficiency standard for the geographic region tested. Income-to-needs values were log-transformed for all analyses, which is common in developmental studies (Noble et al., 2015; Rosen et al., 2018) and reflects the hypothesis that SES associations with cognitive development are strongest at the lower end of the SES spectrum.

We additionally used caregiver education as another measure of SES, coded as total years of education obtained by the caregiver with the greatest educational attainment (10–22 years).

Procedure

Assessments at Time 1 (T1) took place in the participant's home where children completed the battery of EF tasks. Observations of the home environment were also conducted and caregivers provided demographic information, including SES, and information on violence exposure. A longitudinal follow-up (T2) was completed an average of 18 months after the T1 assessment (M = 17.45 months, SD = 4.03), 76 participants (75.2% of the baseline sample) performed the same EF tasks again in the laboratory.

HOME Assessment

Two experimenters visited the family home in order to assess enrichment of the home environment using the Home Observation of the Environment (HOME), Early Childhood version (Bradley et al., 2001). The HOME is made up of both observations by the experimenter and interview questions directed at the parent and a point is given for every item coded as present. The observation component includes information about what the interviewer sees in the home (e.g., books, toys), observations about the parent (e.g., parent's language use), and observations about parent–child interactions (e.g., whether the parent responds verbally to the child's questions). The interview portion contains questions about items the child might have (e.g., puzzles), questions about parent behaviors (e.g., parent encourages child to learn numbers) and questions about parent–child interactions (e.g., parent encourages child to talk and takes time to listen).

We extracted one subscale from the HOME items for further analysis: cognitive stimulation. Several of the original subscales in the HOME assessment (Language Stimulation, Academic Stimulation, Variety, and Learning Materials) include items reflecting cognitive stimulation. Moreover, some of these subscales include items that reflect other aspects of the home environment that reflect constructs other than cognitive stimulation (e.g., parent's voice conveys positive feelings about child, which reflects warmth). As such, we performed a confirmatory factor analysis of the HOME items based on the model of the types of experiences underlying cognitive stimulation—including environmental complexity, enriching experiences, interactions with caregivers, and linguistic experience (Rosen et al., 2019). Cognitive stimulation was made up of 20 items that assessed learning materials and complex stimuli for the child in the home (e.g., the number of books in the home, access to toys that teach numbers), the variety of experiences (e.g., being taken to a museum in the last year, being taken on a trip at least 50 miles away within the last year), language in the home (e.g., whether parent uses complex sentence structure or grammar) and caregiver involvement in the child's learning (e.g., child is encouraged to learn to read a few words, child is encouraged to learn colors). Confirmatory factor analysis indicated that our model of the constructs represented in the HOME items fit the data well (RMSEA < .001, 95% CI [0.000, 0.037]; Tucker–Lewis index = 1.00; comparative fit index: 1.022). See Supporting Information for information on the specific items were included in the cognitive stimulation subscale. Cognitive stimulation was also assessed at Time 2 using a modified version of the HOME short form (Mott, 2004; Rosen et al., 2018).

Language

Although we conceptualize language exposure as a critical element of cognitive stimulation, linguistic experience is measured in a relatively cursory manner in the HOME assessment. Thus, we used an additional task to assess linguistic quantity and quality. Partway through the session, the caregiver and child took a 10-min snack time break that was video recorded. The caregiver was instructed to have a conversation with the child in the same way that they normally would during a snack or meal. Conversations were then transcribed and processed with Systematic Analysis of Language Transcripts software (Salt Software LLC, Madison, WI, USA). To assess language quantity, we used the total number of parent words used during the interaction. To assess language quality, we measured the total number of *different* words, which is an assessment of the diversity of language to which the child is exposed, and the mean length of utterance of the parent, which is a measure of language complexity (Daneri et al., 2018; Hughes & Ensor, 2008). These measures have been used in other studies to assess language quantity and quality in young children (Daneri et al., 2018; Rowe, 2012). One conversation was unintelligible due to excessive background noise and could not be transcribed; this subject was excluded from analyses including language.

Behavioral Measures

Working Memory

Working memory was assessed using a child-friendly version of the backwards digit span task, which has been standardized for children in this age range (Carlson & Meltzoff, 2008). Children were told they would be playing a game where they say things backwards. They were then introduced to an Ernie doll (Sesame Street), for whom the experimenter used a different voice. The experimenter then did an example round with Ernie where the experimenter said two numbers out loud, and Ernie said the string of two numbers presented by the experimenter backwards. Participants then underwent practice trials with two numbers. Once the participants successfully completed one practice round, they moved onto the test trials. If participants did not successfully complete a practice round, they were given scripted feedback and additional instructions on how to complete the task. If participants did not successfully complete a practice round after four trials, they did not move onto the test trials and received a score of zero. The test trials consisted of four levels of increasing difficulty (two-digit, three-digit, four-digit, five-digit) of three trials each. The experimenter presented each trial in a steady tone of voice and the participant's response was recorded. If the participant completed at least one correct trial, they proceeded to the next level. Participants received a point for each correct trial.

Inhibition

To assess inhibition we used a standard test of Simon Says in which participants were instructed to imitate the experimenter's action if the action was proceeded with "Simon says" and to inhibit their response when this phrase was not uttered (Carlson & Meltzoff, 2008). After the rules of the game were introduced, participants responded to a series of questions about the rules to ensure they comprehended them. Participants underwent 10 imitation and 10 inhibition trials, which were intermixed. For imitation trials, participants received three points for each successfully completed action, two points for each partial action, one point for a flinch or wrong movement, and zero point for no movement. For inhibition trials, participants received three points for no movement, two points for a flinch or wrong movement, one point for a partial movement, and zero point for a complete movement. Participants who were unable to pass the practice after four rounds of reminders of the rules were given a score of zero for both imitation and inhibition. Performance was scored by two raters from video recordings and discrepancies were resolved among the two raters; inter-rater reliability was good (Cohen's kappa T1: .76, Cohen's kappa T2: .84).

Cognitive Flexibility

To assess cognitive flexibility, we administered a child-friendly version of a Dimensional Card Sorting Task that has been standardized for children in this age range (Zelazo, 2006) in which children were instructed to sort cards based on color or shape. A box with a blue star and a box with a red truck were placed in front of the participant. Subjects were presented with cards with blue trucks and red stars. During the first round (preswitch), subjects were instructed to sort the cards into the appropriate box based on the color of the shape on the card (five color trials). During the second round (post-switch), the rule switched and participants were instructed to sort the cards by shape (five shape trials). In the third round (switching), the experimenter verbally instructed the participant to sort by shape or by color before each trial (five color trials, five shape trials). In the final round, participants were presented with some cards that had a colored border and some that had no border. Participants were instructed that they should sort by color if the card had a border, and sort by shape if they had a card with no border (five color trials, five shape trials). Subjects moved on to the next round if they got one or fewer wrong answers on the color or shape trials for each level. Participants were then given one point for each level passed for a maximum of four points. One male subject elected not to perform EF tasks and was excluded from analysis including EF measures.

Academic Achievement

During the T2 follow-up, three subsets of the Woodcock–Johnson IV Tests of Achievement were used as assessments of academic achievement (Schrank, Mather, & McGrew, 2014): Letter-Word Identification, Spelling, Calculation. Each test presented the participants with items of increasing difficulty. In the Letter-Word Identification test, participants were asked to identify letters and read lists of words. In the Spelling test, participants were instructed to spell words that were read aloud and used in a sentence by the experimenter. The Calculation test required children to complete a series of arithmetic problems. The Letter-Word Identification, Spelling, and Calculation subsets were all discontinued when the participants answered incorrectly on six consecutive items. Standard scores normed by age were calculated for each subset as measures of the child's achievement in that academic domain and the Academic Skills Cluster was calculated based on these scores.

Violence Exposure

To assess exposure to violence, parents completed the Violence Exposure Scale for Children–Revised (VEX–R; Fox & Leavitt, 1995) in a format adapted for parent rather than child report. This assessment measures the frequency that a child has witnessed violence (e.g., seeing someone be hit really hard; witnessing someone be stabbed or shot) and directly experienced violence (e.g., being beaten up, being pushed or shoved). A total score reflecting the frequency of experiencing or witnessing violence was created by summing the items, and this variable was included as a covariate in all analyses. All analyses presented in the manuscript used the VEX–R as a covariate.

Statistical Analyses

Statistical analyses were performed in SPSS 20 (IBM Corp, Armonk, NY, USA). We had two overarching goals. The first was to examine the role of cognitive stimulation as a mechanism linking childhood SES with EF. To do so, we first tested each of the paths of a standard mediation model. First, we used linear regression to examine the association of SES and EF performance at T1 and at T2, controlling for T1 performance. Specifically, we estimated a series of separate multivariate models examining income-to-needs and parental education as predictors of working memory, inhibition, and cognitive flexibility performance (c path). Next we examined the associations of the two SES measures with cognitive stimulation based on the HOME assessment (i.e., our cognitive stimulation factor) and language exposure (i.e., language quantity using total number of words, and mean length utterance in words, and language quality using number of different words) during the snack time conversation (a path). Finally, we examined the associations of our measures of cognitive stimulation with performance on each of the EF tasks at T1 and T2, controlling for T1 performance (b path). All analyses controlled for age, sex, and violence exposure. Residualized change in EF from T1 to T2 was estimated in all longitudinal models by controlling for performance at T1.

The second goal was to examine whether EF at T1 explained SES-related differences in academic achievement at T2. As such, we additionally tested the associations between SES (income and parental education) and academic achievement as well as the associations between all three measures of EF at T1 with academic achievement at T2.

All results were false discovery rate (FDR) corrected at the level of hypothesis (e.g., to test the hypothesis that SES is related to EF, we performed six tests, so we FDR corrected for those six tests, to a corrected p-value of .05).

Mediation

After testing each of these paths, we used a standard test of statistical mediation that estimates the significance of indirect effects using a bootstrapping approach that provides confidence intervals for the indirect effects (Hayes, 2013). Confidence intervals that do not include 0 are considered evidence for statistically significant indirect effects. We tested the indirect effect for factors significantly associated with both SES and EF.

Sensitivity Analyses

We additionally performed sensitivity analyses controlling for child verbal intelligence as measured by the Peabody Picture Vocabulary Test (PPVT) to determine whether the associations between SES and EF and cognitive stimulation and EF persisted after accounting for verbal ability.

Results

Descriptive Statistics

Means and standard deviations for all study variables are presented in Table 1, and bivariate correlations between all study variables are presented in Table 2.

SES and EF (c Path)

First, we assessed the association between SES and EF at T1. Family SES was positively associated with performance on all three EF tasks. Specifically,

Table 1
Means and Standard Deviations of All Study Variables

Measure	*M*	(*SD*)	Range
Income	$112,530	$64,961	$5,000–$250,000
Income-to-needs	4.73	2.86	.08–10.5
Education	4.04	1.05	10–22
Violence exposure	3.00	3.90	0–20
Cognitive stimulation (total score)	15.69	3.07	5–20
Total number of words	662.07	221.81	291–1,270
Mean length utterance	4.57	0.81	1.71–7.10
Total number of different words	212.44	48.83	43–331
Backwards digit span total points (Time 1)	3.68	2.04	0–8
Backwards digit span total points (Time 2)	5.68	1.80	2–11
Simon says inhibition total points (Time 1)	17.31	10.02	0–30
Simon says inhibition total points (Time 2)	24.04	5.39	0–30
Dimensional card sort highest level passed (Time 1)	2.91	0.90	1–4
Dimensional card sort highest level passed (Time 2)	3.57	0.68	1–4
Academic achievement	100.42	13.39	71–141

Table 2
Correlations of All Study Variables

	Age (T1)	Age (T2)	Sex	Violence	ItN (Log)	Edu	CS	TW	MLU	NDW	BDS (T1)	BDS (T2)	Simon (T1)	Simon (T2)	DCCS (T1)	AA
Age (T1)																
Age (T2)	.702**															
Sex	.007	−.001														
Violence	.063	−.031	.010													
ItN (Log)	.078	< .001	−.016	−.345**												
Edu	−.014	.073	−.093	−.359**	.493**											
CS	−.030	.014	.070	−.174	.474**	.528**										
TW	−.005	−.107	.138	.130	−.072	.094	−.060									
MLU	.064	.067	−.010	−.017	.067	.304*	.194	.611**								
NDW	.045	−.060	.179	.115	.010	.164	.035	.932**	.640**							
BDS (T1)	.214*	.177	.082	−.391**	.418**	.337**	.447**	−.060	.150	−.008						
BDS (T2)	.391**	.323**	.085	−.276*	.356**	.364**	.306**	.040	.201	−.126	.523**					
Simon (T1)	.035	.162	.013	−.317**	.333**	.331**	.380**	.078	.245*	.147	.353**	.323**				
Simon (T2)	−.073	.152	.216	−.071	.057	.118	.337**	−.125	.103	−.076	.133	.320**	.334**			
DCCS (T1)	.108	.125	−.002	−.279**	.339**	.291**	.420**	−.098	.185	−.033	.510**	.351**	.458**	.232*		
DCCS (T2)	.063	.239*	−.028	−.099	.214	.238*	.386**	−.224	.058	−.139	.266*	.266*	.254*	.134	.481**	
AA	−.022	−.167	−.126	−.264*	.279*	.267*	.121	−.130	.006	−.065	.390**	.324**	.088	−.003	.312**	.177

Note. T1 = Time 1; T2 = Time 2; Violence = total score reflecting the frequency of experiencing violence as assessed by the Violence Exposure Scale for Children–Revised (VEX–R); ItN = income-to-needs ratio; Edu = highest level of parental education; CS = cognitive Stimulation as assessed by the Home Observation of the Environment; TW = total words; MLU = mean length utterance in words; NDW = number of different words; BDS = backwards digit span score to assess working memory; Simon = Simon Says score on inhibition trials to assess inhibition; DCCS = Dimensional Change Card Sort highest level passed to assess cognitive flexibility; AA = academic achievement as measured by the Woodcock–Johnson Academic Skills Cluster.
*$p < .05$. **$p < .01$.

income-to-needs and parent educational attainment were associated with working memory performance on the backwards digit span task (β = .299, p = .012; β = .234, p = .019, respectively, Figures 1A and 1B), inhibition as measured by the Simon Says task (β = .251, p = .019; β = .252, p = .019, respectively, Figures 1C and 1D), and cognitive flexibility as measured by the dimensional card sorting task (β = .264, p = .019; β = .219, p = .037, respectively, Figures 1E and 1F). Next, we examined the associations between SES and growth in EF over time. After correction for multiple comparisons, neither measure of SES was associated with change in EF performance from T1 to T2 (ps > .18), although parental education was significantly associated with growth in working memory before FDR correction (β = .219, p = .030, uncorrected).

SES and Cognitive Stimulation (a Path)

Next, we assessed the association between SES and cognitive stimulation at T1. There was a strong positive association between both income-to-needs and parental education with cognitive stimulation as measured by the HOME assessment of (β = .478, p < .001; β = .547, p < .001, respectively, Figures 2A and 2B).

With regard to linguistic experience, we found some evidence for differences in quality, but not quantity, of language exposure as a function of education but not income-to-needs. Specifically, we found that parental education predicted the mean length utterance (β = .294, p = .006), whereas income-to-needs did not (β = .068, p = .670). There was a trend toward an association between

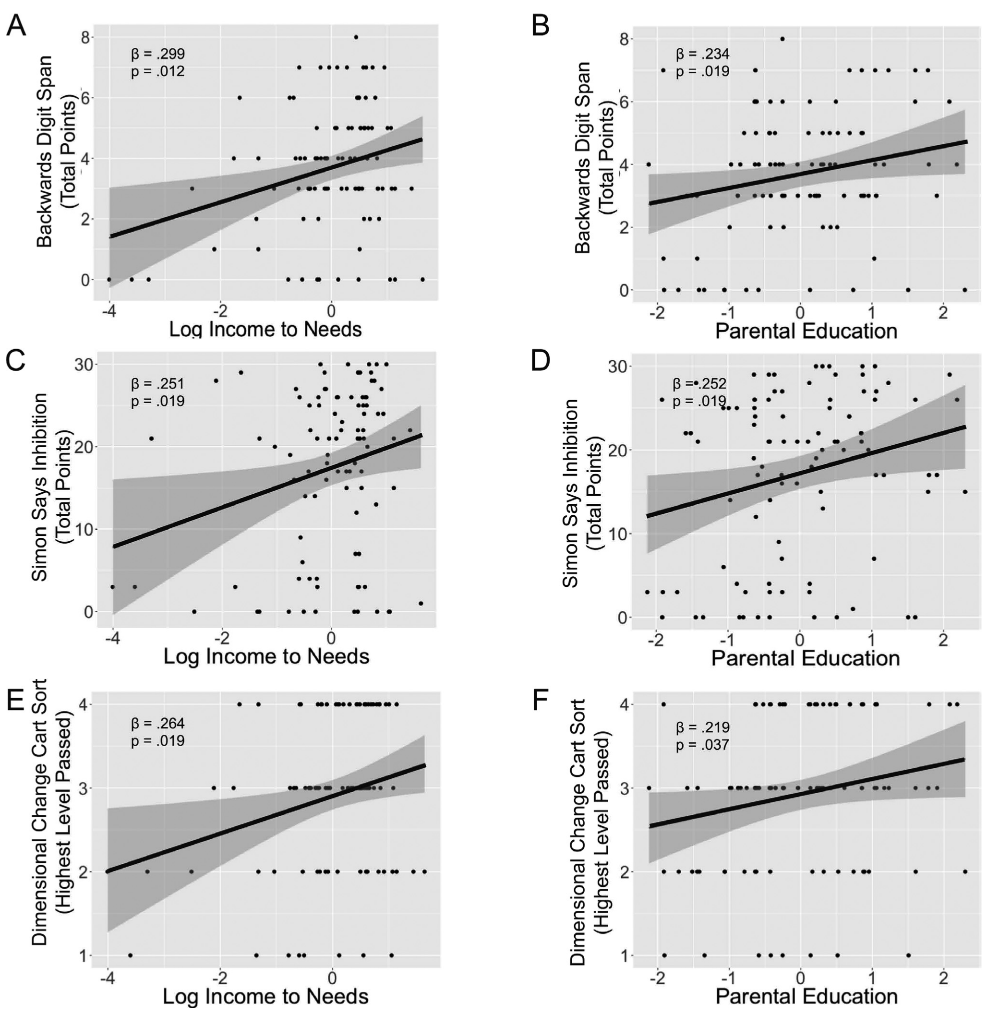

Figure 1. Linear regression between socioeconomic status and working memory (A and B), inhibition (C and D), and cognitive flexibility (E and F), controlling for age, sex, and violence exposure at T1. All p-values are FDR corrected.

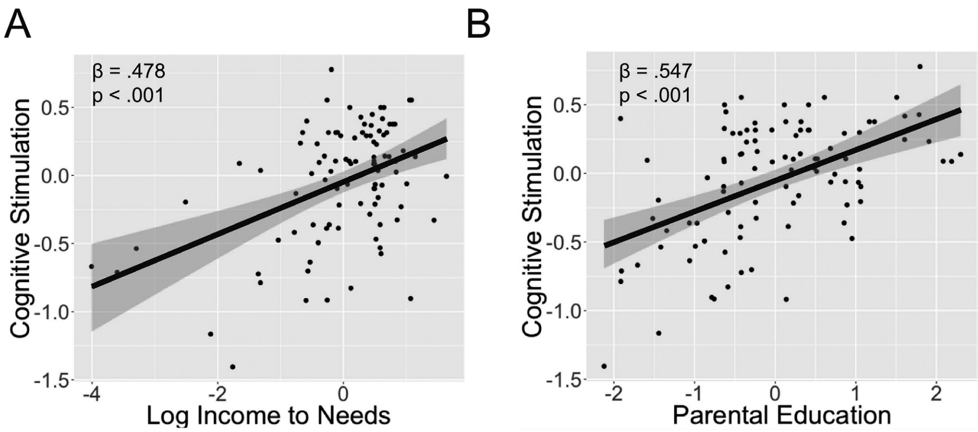

Figure 2. Linear regression between two measures of SES (A) Log Income-to-Needs and (B) Education, with cognitive stimulation in the home environment controlling for age, sex, and violence exposure at T1.

education and number of different words (β = .217, p = .094,), but no significant association between income and number of different words (β = .047, p = .670). Neither measure of SES was associated with language quantity as measured by total number of words (β = −.012, p = .912, β = .140, p = .412 for income-to-needs and education, respectively).

Cognitive Stimulation and EF (b Path)

Cognitive stimulation as measured by the HOME assessment was positively associated with all three measures of EF at T1. Specifically, greater cognitive stimulation in the home was positively associated with working memory performance on backwards digit span (β = .392, p < .001, Figure 3A), inhibition during Simon Says (β = .337, p = .001, Figure 3B), and cognitive flexibility on the dimensional card sorting task (β = .388, p < .001, Figure 3C). Violence exposure was negatively associated with performance in these models (β = −.338, p = .001 for working memory, β = −.263, p = .009 for inhibition, and β = −.220, p = .019), although these associations were consistently smaller than for cognitive stimulation (see Table S1).

Next, we tested the association between linguistic experience and EF at T1. Language complexity as measured by mean length utterance was marginally associated with inhibition after FDR correction (β = .242, p = .078), but not associated with working memory (β = .133, p = .225) or cognitive flexibility (β = .177, p = .148). Language variety as measured by number of different words was not associated with EF (β = .013, p = .938; β = .186, p = .148; β = −.008, p = .938, for working memory, inhibition, and flexibility, respectively). We also investigated whether language quantity as measured by total number of words was associated with EF and found no significant associations with working memory, inhibition, or cognitive flexibility (β = −.18, p = .852; β = .122, p = .675; β = −.063, p = .801, respectively).

We then tested whether cognitive stimulation was associated with growth in EF over time (T2 performance controlling for T1 performance). After FDR correction, cognitive stimulation, as measured by the HOME assessment was associated with growth in cognitive flexibility (β = .268, p = .054) and marginally associated with growth in inhibition (β = .224, p = .087), but not with growth in working memory (β = .141, p = .18). Violence exposure was not associated with growth in EF in any of these models (ps > .42). Neither language quantity nor either measure of language quality was associated with growth in any measure of EF (ps > .28), nor was language quantity associated with growth in any measure of EF (ps > .12). Additionally, EF at T1 did not predict changes in cognitive stimulation measured at T2, controlling for T1 cognitive stimulation (ps > .5), which is inconsistent with the idea that higher EF is driving higher cognitive stimulation from parents.

Mediation Analyses (c′ Path)

Finally, we conducted mediation analyses to determine whether the degree of cognitive stimulation in the home environment mediated the association between family SES and EF (Figure 4). Consistent with our hypotheses, we found a significant indirect effect of income-to-needs (95% CI [0.15, 0.62]) and parental education (95% CI [0.09, 0.24]) on working memory performance and cognitive flexibility (95% CI [0.07, 0.27] for income-to-needs and 95% CI [0.03, 0.11] for parental education) through cognitive stimulation. We also found a significant indirect effect of income-to-needs (95% CI [0.42, 2.90]) on inhibition through cognitive stimulation. Furthermore, there was a significant indirect effect of parental education on inhibition through cognitive stimulation and mean length utterance (95% CI [0.07, 1.09]).

Sensitivity Analyses

We conducted sensitivity analyses to determine whether these associations persisted after controlling for verbal ability as measured by the PPVT. The findings were largely unchanged. Briefly, cognitive stimulation is associated with performance on all three tests of EF at T1 after controlling for verbal ability. Both measures of SES have indirect effects on all three measures of EF through cognitive stimulation at T1. Additionally, there is a marginally significant association between cognitive stimulation and growth in both inhibition and cognitive flexibility at T2 after controlling for verbal ability. Detailed results are presented in the Table S2.

SES and Academic Achievement

We next assessed whether SES at T1 was associated with academic achievement at T2. SES was

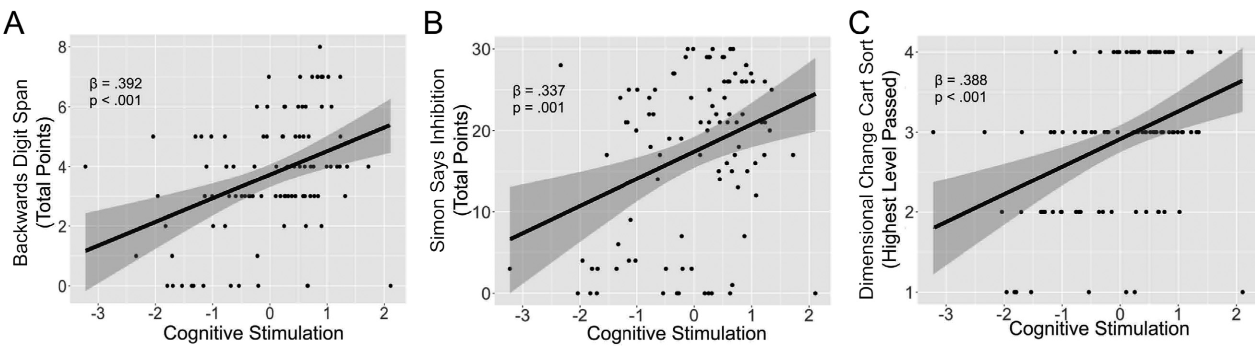

Figure 3. Linear regression between cognitive stimulation and working memory (A), inhibition (B), and cognitive flexibility (C), controlling for age, sex, and violence exposure at T1. All *p*-values are FDR corrected.

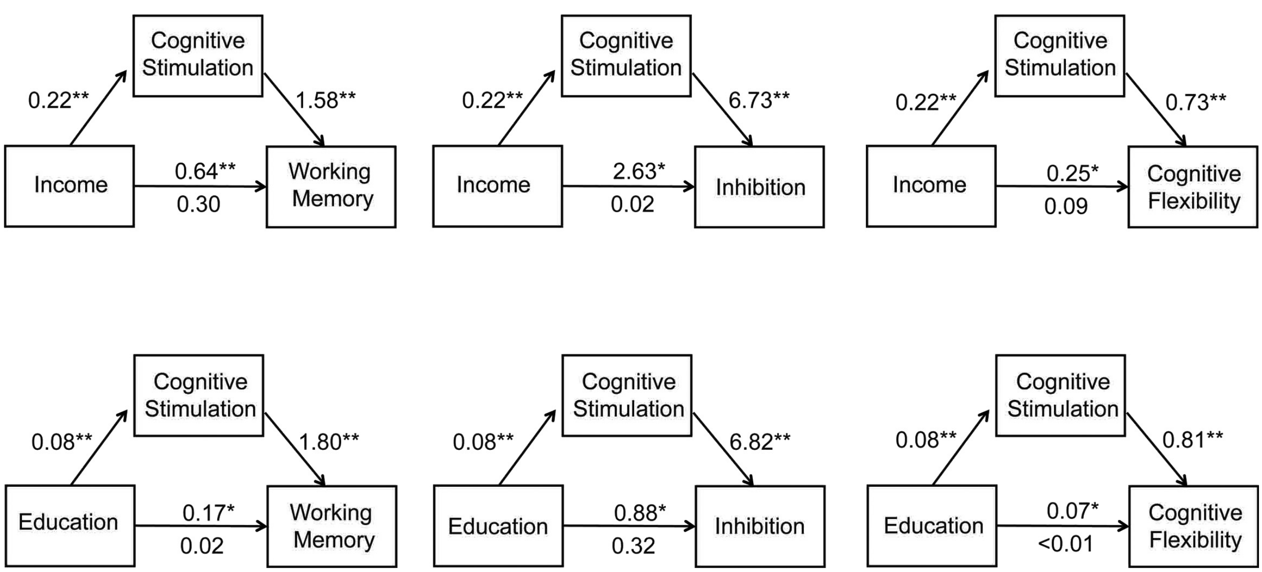

Figure 4. Mediation models. Cognitive stimulation fully mediated the associations between socioeconomic status (income-to-needs and education) and executive functions (working memory, inhibition, and cognitive flexibility) at T1. Coefficients are unstandardized. **p* < .05. ***p* < .01.

marginally associated with academic achievement ($\beta = .222$ $p = .061$ and $\beta = .215$, $p = .061$, for income and education, respectively).

EF and Academic Achievement

We next assessed the associations between EF at T1 and academic achievement at T2. Working memory and cognitive flexibility were both positively associated with academic achievement ($\beta = .398$, $p = .003$ and $\beta = .286$, $p = .017$, respectively), whereas inhibition was not ($\beta = .141$, $p = .666$).

Mediation Analyses

Finally, we conducted mediation analyses to determine whether EF explained SES-related differences in academic achievement (Figure 5). We found that working memory significantly mediated the association between income-to-needs and academic achievement (95% CI [0.42, 4.03]). At a more liberal threshold, working memory mediated the association between education and achievement (90% CI [0.004, 0.89]). Cognitive flexibility also mediated the association between income-to-needs and education with achievement at a more liberal threshold (90% CI [0.11, 2.20] and 90% CI [0.01, 0.64], respectively).

Discussion

This study adds to a small but growing literature highlighting an important role of cognitive stimulation in the early home environment in the development of EF. We investigated cognitive stimulation —assessed with observational measures of environmental complexity, caregiver interactions, and language quality and quantity—as a mechanism explaining SES-related differences in the development of EF in children. Consistent with previous studies, SES was associated with working memory, inhibition, and cognitive flexibility (Dilworth-Bart, 2012; Hackman & Farah, 2009; Lawson et al., 2018; Noble et al., 2007; Rosen et al., 2018). At T1, SES was also strongly associated with cognitive stimulation in the home environment, such that income-to-needs and parental education were positively associated with our observational measure of cognitive stimulation; parental education was additionally associated with parent language quality. Cognitive stimulation, in turn, was positively associated with working memory, inhibition, and cognitive flexibility, whereas language quality was specifically associated with inhibition. Consistent with our hypotheses, cognitive stimulation mediated the concurrent associations at T1 between both measures of SES and all three measures of EF. Moreover, cognitive stimulation at T1 was significantly associated with growth in inhibition and cognitive flexibility over an 18-month follow-up period, whereas SES was not associated with growth in EF. Critically, our results remained largely unchanged when we included verbal intelligence as a control variable in our analyses. These findings provide the first longitudinal evidence using observational assessment of the home environment indicating that cognitive stimulation in the home environment is associated with the development of two core aspects of EF. The significant associations of cognitive stimulation with growth in EF over time are notable, given that SES associations with EF emerge early and remain relatively stable over time (Hackman et al., 2015; Lengua et al., 2015). We additionally demonstrate that variation in working memory and cognitive flexibility predicts future academic achievement, and that working memory and flexibility mediate the association between income and achievement. These findings suggest that cognitive stimulation may be an important target for interventions aimed at reducing the SES gap in EF and that the resulting improvements in EF may have a downstream impact on academic achievement.

Here, we replicate and extend previous studies demonstrating that cognitive stimulation is a mechanism explaining SES-related differences in EF. Sarsour et al. (2011) found that exposure to enriching activities—an aspect of cognitive stimulation included in this study—mediated the cross-sectional association between SES and working memory and inhibition in older children, aged 8–12 years. Furthermore, recent work from Amso et al. (2018) demonstrated that cognitive stimulation mediated

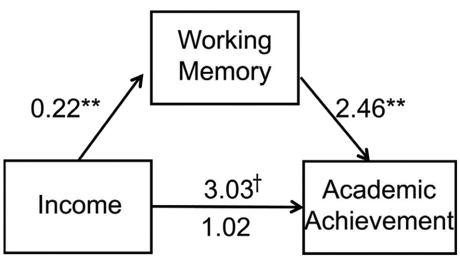

Figure 5. Academic achievement. Working memory fully mediated the association between income-to-needs and academic achievement. Coefficients are unstandardized. †$p < .1$. *$p < .01$. **$p < .05$.

the association between SES and working memory. We extend these cross-sectional findings by demonstrating that cognitive stimulation is associated with *growth* in EF during early childhood. The only prior longitudinal study on this topic found that cognitive stimulation as measured by parent report of learning materials, variety of experiences, and academic stimulation mediated the association between SES and working memory and planning (Hackman et al., 2015). We extend this prior work using observational measures of cognitive stimulation and by documenting the mediating role of cognitive stimulation in the link between SES and two additional aspects of EF: inhibition and cognitive flexibility (Miyake et al., 2001). We further extend this work by demonstrating that cognitive stimulation in the home environment is associated with growth in EF over time.

Consistent with other studies we demonstrate that cognitive stimulation mediates SES-related differences in working memory performance measured concurrently (Amso et al., 2018; Sarsour et al., 2011). However, we did not find that cognitive stimulation predicted growth in working memory in an 18-month follow up. Given that recent evidence suggests that cognitive stimulation plays an important role in explaining SES-related differences in working memory performance in older children and adolescents (Amso et al., 2018), one possibility is that there are developmental differences in the importance of cognitive stimulation across the different components of EF. However, future longitudinal studies beginning earlier in development would be needed to address this question.

The findings of this study highlight that the home environment has a pronounced role in the development of cognitive abilities in early childhood. Cognitive stimulation in school and other environments is likely important for the development of EF, but early in development the most proximal context is in the home environment. As children develop and spend more time in other contexts, however, the importance of cognitive stimulation outside the home may increase (Crosnoe et al., 2010). Therefore, future longitudinal studies should examine the role of cognitive stimulation in the classroom as an additional mechanism underlying growth in EF over time among school-aged children.

This study also extends this previous work by including both a measure of parental language, a critical aspect of cognitive stimulation. Our findings are somewhat consistent with a recent study that found maternal language complexity mediated the association between SES and a composite score of child EF (Daneri et al., 2018). In contrast, we found a specific link between language complexity, as measured by mean length utterance, and inhibition, but not working memory or cognitive flexibility. Although the mechanisms underlying this association are unknown, one possibility is that greater complexity of parent language may facilitate the development of inhibition in children by requiring them to suppress a response for a longer period of time during a conversation to wait for the speaker to complete their turn (McLaughlin, 2016). Greater complexity of language exposure may also increase children's ability to internally represent regulatory speech, which could be used to help with inhibition of a prepotent response (Peterson, Bates, & Staples, 2015; Valloton & Ayoub, 2011).

Considerable evidence suggests that cognitive stimulation provides the building blocks for development of EF in childhood. Given the meaningful role that caregivers play in shaping the amount of cognitive stimulation children experience early in development, it has been argued that in environments with limited caregiver interactions, children have less external guidance to regulate attention and have fewer experiences that require attention to be sustained (Rosen et al., 2019). This reduced caregiver interaction coupled with reduced access to sensory complexity (e.g., reduced access to books, toys, and complex stimuli with which to engage) may result in delayed development of attention regulation mechanisms and language ability in children. The development of these lower order cognitive functions may in turn, scaffold development of higher order cognitive abilities including EF. A recent study highlighted other lower order functions, such as children's experiences in directing their attention in anticipation of impending events, as building blocks for EF (Weiss, Meltzoff, & Marshall, 2018).

Indeed, it is well-established that far more extreme environments lacking in cognitive stimulation and caregiver interaction, such as institutional rearing and neglect, are associated with large and lasting difficulties with EF (Bos, Fox, Zeanah, & Nelson, 2009; Loman et al., 2013; McLaughlin, Sheridan, & Nelson, 2017; Tibu et al., 2016). Even children who are removed from these types of deprived environments and placed in a more cognitively stimulating environment before the age of 24 months exhibit attentional impairments in late childhood and early adolescence (Slopen, McLaughlin, Fox, Zeanah, & Nelson, 2012; Tibu et al., 2016). Furthermore, recent evidence suggests that increasing cognitive stimulation in the home is an effective strategy in improving EF in childhood. A randomized controlled trial in Pakistan found that an intervention designed to improve cognitive stimulation in the home environment was associated with gains in EF skills over time and this effect was stronger than a nutrition intervention (Yousafzai et al., 2016). Together, this work highlights the critical role of cognitive stimulation in the home in supporting the development of EF.

It is notable that our measure of cognitive stimulation included both items that reflect access to resources that are important for learning (e.g., Child has toys that teach colors) as well as items that reflect parental engagement in learning (e.g., Child is encouraged to learn numbers). We believe that access to learning materials coupled with parental engagement in learning together scaffold development of EF in children. It is unlikely that SES-related differences in EF would be mitigated by simply providing families with learning materials without simultaneously providing parents with information on effective ways of engaging with their child as well as work to eliminate the structural barriers that constrain time for parent-child interactions. However, future studies would be needed to test this hypothesis directly.

Recent work has sought to disentangle how distinct dimension of childhood adversity, including deprivation and threat, may be associated with different cognitive and neural outcomes (McLaughlin et al., 2014; Sheridan & McLaughlin, 2014). This study sought to examine the associations of cognitive stimulation with EF after controlling for exposure to violence. We hypothesized that cognitive stimulation would be the environmental factor most strongly related to EF and growth in EF over time, and our results support this hypothesis. We also found that violence exposure was associated with EF at baseline, though to a lesser degree than cognitive stimulation. A cross-sectional association of violence with EF is consistent with some previous work (Hanson et al., 2010) but contrasts with several recent studies in large sample demonstrating an absence of association between violence exposure and EF—including working memory, inhibition, and cognitive flexibility—in adolescents after controlling for SES (e.g., Lambert et al., 2017; Sheridan, Peverill, Finn, & McLaughlin, 2017). The fact that we observed residual associations of violence exposure with EF in our sample of young children may suggest that violence exposure has a more powerful effect on EF early in development or that these effects become weaker across development (but see Machlin, Miller, Snyder, McLaughlin, & Sheridan, 2019). Future studies with samples spanning a wider age range are needed to evaluate this possibility empirically. Critically, only cognitive stimulation was associated with growth in EF, suggesting that interventions targeting cognitive stimulation are likely to be most effective in mitigating SES related differences in the development of EF.

This study has several limitations that should be acknowledged. First, our language assessment was short in length (10 min) and potentially limited in its content. Parents often took a few minutes to get comfortable and conversations often focused on talking about the prizes children had just won or asking about the games they had played. Therefore, it is likely that these conversations did not fully capture a natural everyday snapshot of language exposure. A more open-ended conversational period like the book-sharing task employed by Daneri et al. (2018) might provide a more realistic picture of language exposure in the home. Alternatively, Language Environment Analysis (LENA) technology can track language exposure over a 16 hr period and provide a potentially more representative sample of language exposure and language exposure has been shown to vary by SES using LENA (Gilkerson et al., 2017; Ramírez-Esparza et al., 2014; Romeo et al., 2018). Indeed, others have recently found that children's language exposure and experience as measured by LENA is predictive of language ability and prefrontal cortex function (Romeo et al., 2018). Future studies should employ these tools to explore the role of language exposure in SES-related differences in working memory, inhibition, and cognitive flexibility. Second, we had a relatively large range in time between the first wave and the follow-up time. This range limits the precision of this study and future studies should work to have more precise timing between study waves. Third, while our sample was diverse with respect to income, the sample was relatively highly educated. While we still found significant associations between education and both cognitive stimulation and EF and results were consistent across measures of SES, future studies should work to replicate the present findings with a more educationally diverse sample. Fourth, EF develops rapidly during this period of development and as such, another limitation is that that ceiling effects may have constrained variability in inhibition and cognitive flexibility scores at T2. Finally, while the present findings extend previous work that cognitive stimulation in the home explains SES related differences in EF in younger children, many studies have demonstrated SES-related differences in EF emerge much earlier in development (e.g., Lengua et al., 2015).

Therefore, future studies should aim to replicate these findings in an even younger sample.

Conclusions

This study highlights the important role that cognitive stimulation plays in the development of EF and that differences in working memory play a meaningful role in explaining SES-related differences in academic achievement in early childhood. These findings along with other recent studies (Daneri et al., 2018; Hackman et al., 2015; Sarsour et al., 2011; Yousafzai et al., 2016) point to cognitive stimulation as a plausible and modifiable environmental mechanism that contributes to these SES-related differences in cognitive development. Additionally, understanding how cognitive stimulation impacts the brain systems that support EF may shed light onto the neural mechanisms underlying SES-related differences in cognitive development. Indeed, recent work has shown that cognitive stimulation is associated with greater cortical thickness in the frontoparietal network (Rosen et al., 2018). Together with this study, these findings point to cognitive stimulation as an important mechanism that contributes to SES-related disparities in cognitive development, particularly EF. Interventions that target cognitive stimulation may be promising for reducing SES-related disparities in both EF and academic achievement.

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Supporting Information

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

Table S1. Regression Analyses Including Socioeconomic Status, Violence Exposure, and Cognitive Stimulation in the Same Model

Table S2. Sensitivity Analyses Controlling for Verbal Intelligence