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# Additive and Synergistic Relations of Early Mother–Child and Caregiver–Child Interactions for Predicting Later Achievement

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This study examines associations between stimulating–responsive social interactions with mothers and nonparental childcare providers during the first 3 years of life and children's vocabulary and mathematics skills through age 15 ($N$ = 1,364). Additive relations were found in which more stimulating–responsive interactions with mothers and with caregivers were linked to higher mathematics achievement in childhood and adolescence. More stimulating–responsive early interactions with mothers were also associated with larger child vocabularies through age 15. Synergistic relations, consistent with the dual-risk hypothesis, also were found. Children whose early interactions with both mothers and caregivers were low in stimulation and responsivity had substantially lower mathematics skills. Implications for early childhood interventions and policies are discussed.

*Keywords:* mother–child interaction, caregiver–child interaction, early childcare, vocabulary, mathematics

*Supplemental materials:* http://dx.doi.org/10.1037/dev0000824.supp



Developmental theory and empirical research have emphasized the importance of early life experiences for children's later development (Fraley, Roisman, & Haltigan, 2013; Golinkoff & Hirsh-Pasek, 2000; Phillips & Shonkoff, 2000; Raby, Roisman, Fraley, & Simpson, 2015; Shonkoff et al., 2012). The current study extends this research by examining relations between stimulating–responsive social interactions with mothers and nonparental childcare providers (i.e., caregivers) during the first 3 years of life and children's vocabulary and mathematics achievement from age 4.5 through 15 years. Specifically, our primary focus is to examine the extent to which interactions with mothers and caregivers are linked to children's later skills from age 4.5 to 15 years in ways that appear to be additive (i.e., no moderation) or synergistic (i.e., moderation). We also examine to what extent the effects associated with the first 3 years persist or fadeout from age 4.5 to 15 years and whether they are attenuated when stimulating–responsive interactions at age 4.5 years are added to the model.

## Are There Additive or Moderated Relations Between Early Mother–Child and Caregiver–Child Interactions With Later Achievement?

A robust literature points to both short- and long-term associations between stimulating–responsive mother–child interactions during the first 3 years and children's vocabulary and mathematics skills (Ayoub, Vallotton, & Mastergeorge, 2011; Burchinal, Vernon-Feagans, Cox, & the Key Family Life Project Investigators, 2008; NICHD Early Child Care Research Network [ECCRN], 2000b; Rafferty, Griffin, & Lodise, 2011). For instance, Fraley et al. (2013) reported associations between maternal sensitivity during the first 3 years and children's social competence and academic skills through age 15, associations that were not explained by maternal sensitivity in middle childhood or adolescence. Early caregiver–child interactions have also been linked to early language and cognitive abilities (Burchinal, Roberts, Nabors, & Bryant, 1996; Li, Farkas, Duncan, Burchinal, & Vandell, 2013; NICHD ECCRN, 2000b). In research utilizing the Study of Early Child Care and Youth Development (SECCYD) dataset, the behavioral counts of caregivers' language and cognitive activities with specific children predicted their language comprehension,

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mathematics skills, and expressive vocabulary at 4.5 years (NICHD ECCRN, 2003).

Relatively few studies have considered how early mother–child and caregiver–child interactions, together, are linked to later child developmental outcomes. However, the available research underscores the value of considering joint effects of children's experiences with mothers and caregivers. There is evidence of additive or cumulative effects in which both mother–child and caregiver–child interactions during early childhood are significant positive predictors of children's cognitive and language outcomes at age 3 years (NICHD ECCRN, 2000b), 4.5 years (NICHD ECCRN, 2003), and first grade (Hirsh-Pasek & Burchinal, 2006). If the relations are additive (i.e., no moderation), then high-quality interactions with caregivers would be associated with higher cognitive and language outcomes regardless of the quality of interactions with mothers (and vice versa). In other research that considers both mother–child and caregiver–child interactions, there is evidence of moderated relations in which effects associated with early caregiver–child interactions on early childhood outcomes (Vernon-Feagans, Bratsch-Hines, & The Family Life Project, 2013) and adolescent outcomes (Burchinal, Lowe Vandell, & Belsky, 2014) are moderated by mother–child interactions. If relations are synergistic (i.e., moderation), then relations between high-quality interactions with caregivers and children's cognitive and language outcomes would be conditional on the quality of the interactions with mothers (and vice versa).

Two moderated models derived from the work of Rutter (1987) are considered in the current study. The compensatory model hypothesizes that stimulating–responsive interactions with one adult can compensate for less stimulating–responsive interactions with another adult. Thus, positive caregiving from childcare providers may off-set poor quality interactions with mothers or stimulating–responsive interactions with mothers may off-set or compensate for lower quality interactions with caregivers. The dual-risk hypothesis posits that receiving little stimulation and responsivity from both mother and caregiver may be particularly detrimental for young children because of synergistic effects.

There is some evidence consistent with both the compensatory and the dual-risk hypotheses. For example, using data from the Family Life Project, Vernon-Feagans and colleagues (2013) found higher quality caregiver–child language interactions buffered the effects of lower quality mother–child language interactions on children's language outcomes. These relations were found at both the 36- and 48-month waves of data. Similarly, Miller and colleagues (2014) found evidence of compensatory effects of Head Start participation for children who received lower levels of academic stimulation in their homes. Also, consistent with the compensatory hypothesis were findings reported by Dearing, McCartney, and Taylor (2009) in which low-income children who attended higher quality child care demonstrated higher academic achievement in middle childhood than other low-income students. Evidence consistent with the dual-risk hypothesis was reported by Nelson and colleagues (2007) who found experiences of extreme deprivation were exacerbated when children continued to be exposed to depriving living conditions but could be partially ameliorated if living conditions improved. The current study extends this prior research by examining the potential additive and synergistic effects of mother–child and caregiver–child interactions during the first 3 years and children's vocabulary and mathematics achievement through age 15 years.

## Developmental Timing and the Enduring Associations of Early Experiences

Although a central and enduring theme in developmental science, the research examining effects associated with early experience is limited in several respects. First, there is lack of consistency regarding the period of time represented by "early experience." Whereas some investigators have considered the cumulative effects associated with the first 5 years of life (Campbell, Pungello, Miller-Johnson, Burchinal, & Ramey, 2001; Vandell et al., 2010), others have emphasized the preschool period with a focus on 3 and 4 year old children (Diamond, Barnett, Thomas, & Munro, 2007; Schweinhart, 1993). Still others have emphasized the importance of children's experiences in the first 3 years (Fraley et al., 2013; Hirsh-Pasek et al., 2015; Longo, McPherran Lombardi, & Dearing, 2017; Lupien, McEwen, Gunnar, & Heim, 2009; Raby et al., 2015). In the current article, we focus on children's interactions with their mothers and caregivers in the first 3 years with follow-up analyses that include interactions in the later preschool period.

The focus on the first 3 years was motivated, in part, by evidence from neuroscience that brain development may be particularly susceptible to serve-and-return exchanges that occur when infants and toddlers interact with adults who respond to their vocalizations, cries, smiles, and interests (Fox, Levitt, & Nelson, 2010; Shonkoff, 2010). In addition, exposure to language-rich environments during the first 3 years has been identified as critical for language development, and differences in language input and conversational turn-taking have been related to later differences in children's vocabulary and reading skills (Gilkerson et al., 2018; Hirsh-Pasek et al., 2015), as well as children's brain activation in the Broca's area (Romeo et al., 2018). A final motivation for the current study is a closer examination of persistence versus fadeout of effects associated with early experiences. Although there are influential reports of enduring impacts of stimulating–responsive experiences during early childhood into adulthood for low-income children (Heckman, Pinto, & Savelyev, 2013; Schweinhart, 1993), other studies have found early childhood effects fadeout shortly after children move on to formal schooling (Bailey, Duncan, Odgers, & Yu, 2017). Identifying conditions under which early experiences are carried forward or fadeout are needed to advance both developmental theory and inform practice.

## Current Study

To summarize, the current study extends prior research in several ways. First, we examine if early stimulating and responsive interactions with mothers and caregivers have additive or synergistic relations with children's vocabulary and mathematics skills from age 4.5 to 15 years. Second, we ask if early stimulating–responsive interactions are associated with children's mathematics skills and vocabulary in substantively different ways at five time points from early childhood to adolescence (i.e., age 4.5 years, Grades 1, 3, 5, and age 15 years). Specifically, we examine if relations between early interactions and later vocabulary or mathematics competencies are persistent or fade over time or are

apparent at some ages but not others. Third, we consider if associations for the first 3 years and later outcomes are attenuated after including mother–child and caregiver–child interactions at age 4.5 years. Because of the study's correlational design, we include a number of covariates that may account for the associations between early life experiences and later vocabulary and mathematics skills, including child gender and ethnicity, maternal vocabulary, maternal education, family income, household structure, maternal depression, parenting stress, separation anxiety, and maternal health.

## Method

### Participants

The current study uses data from the SECCYD, an archived dataset available at https://www.icpsr.umich.edu/icpsrweb/ICPSR/series/00233. Participants were recruited during hospital visits conducted with mothers shortly after the birth of a child in 1991 at 10 locations in the United States (Little Rock, AR; Irvine, CA; Lawrence, KS; Boston, MA; Hickory, NC; Philadelphia, PA; Pittsburgh, PA; Charlottesville, VA; Seattle, WA; Madison, WI). During selected 24-hr intervals, all women giving birth ($N$ = 8,986) were screened for eligibility. Of those families, 3,142 were excluded due to a priori criteria such as not English speaking or plans to move within the next 3 years. At a follow-up telephone interview at 2 weeks, 1,353 could not be contacted or refused to participate. Families were randomly selected among the remaining pool of eligible participants. A total of 1,364 families were recruited, completed a home interview at 1 month, and became the study participants. Overall, this constituted a 52% response rate from the original approach to families in the hospital to successful recruitment in the study.

At recruitment, 26% of the mothers had no more than a high school education; 21% had incomes no greater than 200% of the poverty level; and 22% were of minority race or ethnicity (i.e., not non-Hispanic White). See Table 1 for sample descriptive statistics. For more details about the sample and sample recruitment, see NICHD ECCRN (2005a). The current study received Institutional Review Board approval at University of California, Irvine (Study of Early Child Care and Youth Development: HS 2006–5347).

Table 1
*Child, Family, and Childcare Covariates Included in the Analyses*

| Covariates | *n* | *M* | *SD* | Range |
|---|---|---|---|---|
| Male (%) | 1,364 | 51.69 | | |
| White (%) | 1,364 | 80.43 | | |
| Black (%) | 1,364 | 12.90 | | |
| Hispanic (%) | 1,364 | 4.69 | | |
| Other (%) | 1,364 | 1.98 | | |
| Maternal education[a] | 1,363 | 14.23 | 2.51 | 7–21 |
| Maternal age[a] | 1,364 | 28.11 | 5.63 | 18–46 |
| Parenting stress[b] | 1,275 | 50.23 | 9.90 | 26–83 |
| Maternal PPVT[c] | 1,167 | 99.01 | 18.35 | 40–159 |
| Separation anxiety[d] | 1,300 | 65.42 | 12.72 | 29–104.33 |
| Maternal depression[e] | 1,303 | 9.26 | 6.93 | 0–43 |
| Income-to-needs[e] | 1,302 | 3.62 | 2.87 | .14–22.47 |
| Father in the home[e] | 1,305 | .82 | .35 | 0–1 |
| Maternal health[e] | 1,305 | 3.17 | .56 | 1–4 |
| CC hours 6 | 864 | 34.10 | 15.22 | 1–99 |
| CC hours 15 | 909 | 34.69 | 16.02 | 1–100 |
| CC hours 24 | 922 | 35.14 | 15.47 | 0–100 |
| CC hours 36 | 996 | 34.00 | 16.80 | 1–148 |
| GP CC[e] | 1,074 | .12 | .28 | 0–1 |
| Home CC[e] | 1,074 | .43 | .43 | 0–1 |
| Center CC[e] | 1,074 | .24 | .36 | 0–1 |

*Note*. CC = childcare; GP = grandparent.
[a] From the 1-month assessment wave. [b] From the 6-month assessment wave. [c] From the 36-month assessment wave. [d] Average of 6-, 15-, and 24-month assessment waves. [e] Average of 6-, 15-, 24-, and 36-month assessment waves.

### Procedure

The current study utilizes measures from the SECCYD that were collected when children were 1 month to 15 years. We first describe our two primary independent variables of interest: stimulating–responsive mother–child interactions and stimulating–responsive caregiver–child interactions. We then describe our two primary dependent variables of interest: vocabulary and mathematics achievement. Then we present the covariates included in the analyses.

**Mother–child interactions.** Observational assessments of mother–child interactions were conducted when the study children were 6, 15, 24, and 36 months old. At age 6 and 15 months, the videotaped interactions occurred in the home. At age 24 and 36 months, the videotaped interactions occurred in a lab setting (for more detailed descriptions of these procedures, see NICHD ECCRN, 1999, 2000a). At each age, the videotaped interactions were 15 min in duration. At age 6 months, the interaction was divided into two segments: 7 min to 8 min where the mother chose toys to use while interacting with the child, and 7 min to 8 min where the mother was given a standard set of toys (e.g., rattle with faces). At the age 15-, 24-, and 36-month observations, mothers were asked to provide their child with toys from 3 bags in a set order. At ages 15 and 24 months, the toys were a storybook (differed at 15 months and 24 months) in the first bag, a toy stove in the second bag, and a toy house in the third bag. At age 36 months, the toys included washable markers in the first bag, dress-up clothes in the second bag, and Dublo blocks in the third bag. Mothers were told that this part of the visit would last 15 min and that their child should spend some time with the toys in each bag, starting with the first bag. They were not explicitly told to play with their child nor were they told how much time their child was to spend with each toy.

All of the videotaped mother–child interactions were coded at a single site by teams of five to six coders who received extensive training and met regularly to maintain reliability. At 6, 15, and 24 months, the coders used four-point scales to rate four aspects of maternal behavior (maternal stimulation, sensitivity to nondistress, positive regard, and intrusiveness [reverse coded]) that were summed to create a composite variable representing stimulating–responsive mother–child interaction at each of these three ages. At 36 months, seven-point scales were used by coders to rate four aspects of maternal behavior (maternal stimulation, supportive presence, hostility [reverse coded], and respect for autonomy), which were summed. Alphas ranged from .70 to .82 across the four ages (Hirsh-Pasek & Burchinal, 2006). Previous studies have found these ratings of stimulating–responsive mother–child interaction to be related to children's cognitive and language skills in

early childhood and middle childhood (Hirsh-Pasek & Burchinal, 2006; NICHD ECCRN, 2005b).

**Caregiver–child interactions.** At 6, 15, 24, and 36 months, children who experienced nonparental care on a routine basis for 10 or more hours a week were observed in that care setting for two half-day visits at each age period (resulting in up to eight half-day visits) per child. Within each half-day visit, observers conducted two 30-min observations using the Behavioral Frequency portion of the Observation Record of the Caregiving Environment (ORCE) for a total of four 30-min observations distributed over 2 days at each age period that the study child was in routine nonparental care (NICHD ECCRN, 2000a; Vandell & NICHD ECCRN, 1996).

The behavioral frequency codes were scored using a time-sample procedure in which observers observed for 30 s and then recorded for 30 s. For each 30-s record period, coders marked if the following caregiver behaviors had occurred during the previous observed interval: ask questions, speak positively to the child, respond to child vocalization or talk, positive talk, other talk, reads aloud to child, cognitive stimulation, social stimulation, and teaches academic skills (at the 24 and 36 month waves). At each age period (e.g., 6 months), the frequency of the specific behaviors (e.g., ask questions) were summed over the 30-min observation, standardized, and then summed to create a composite measure of stimulating–responsive caregiver–child interaction (for means, standard deviations and ranges, see Table 2). Because each behavior contributing to the composite was standardized before summing, negative and positive values for each scale were contributing to the composite scores and mean scores could differ from 0 (unlike if standardization happened after the summing of the specific behaviors). Standardized Cronbach's alphas were .78 at 6 months, .82 at 15 months, .78 at 24 months, .75 at 36 months, and .68 at 54 months.

Childcare observers were trained at a central location and certified as reliable coders using both live and videotaped assessments before conducting the live behavioral observations in the field (NICHD ECCRN, 2000a). Additionally, there were checks every 3 to 4 months for observer drift. Interobserver agreement with the master coders ranged from .86 to .99. Prior research has found significant relations between the behavioral frequency observations of stimulating–responsive interactions with caregivers and children's cognitive and language performance at 36 and 54 months (NICHD ECCRN, 2000b, 2003). The global ratings of the ORCE have been linked to children's achievement outcomes at age 15 (Vandell et al., 2010) and at the end of high school (Vandell, Burchinal, & Pierce, 2016). The purpose of the current study is to determine if the behavioral ratings of the ORCE extend to children's language and mathematics skills in middle childhood and adolescence, and to what extent they moderate associations of early mother–child interactions and these outcomes.

Table 2
*Mother–Child Interactions, Caregiver–Child Interactions, and Performance on Later Competencies*

| Key variables | *n* | *M* | *SD* | Range |
|---|---|---|---|---|
| MCI 6 months | 1,272 | 11.81 | 2.15 | 4–16 |
| MCI 15 months | 1,240 | 12.06 | 1.99 | 4–16 |
| MCI 24 months | 1,172 | 12.07 | 2.27 | 4–16 |
| MCI 36 months | 1,161 | 21.65 | 3.84 | 5–28 |
| CCI 6 months | 487 | −.09 | 2.60 | −5.71–7.82 |
| CCI 15 months | 520 | −.37 | 6.87 | −17.40–28.67 |
| CCI 24 months | 553 | −.25 | 5.72 | −22.80–21.75 |
| CCI 36 months | 594 | −.44 | 5.35 | −14.49–23.93 |
| VOC 54 months | 1,060 | 100.24 | 15.03 | 10–143 |
| VOC grade 1 | 1,020 | 105.46 | 15.57 | 44–151 |
| VOC grade 3 | 1,014 | 105.47 | 14.80 | 34–152 |
| VOC grade 5 | 992 | 103.09 | 14.78 | 29–155 |
| VOC age 15 | 889 | 99.93 | 14.77 | 34–158 |
| MATH 54 months | 1,053 | 102.94 | 15.63 | 41–153 |
| MATH grade 1 | 1,023 | 110.80 | 17.14 | 46–163 |
| MATH grade 3 | 1,013 | 115.05 | 15.00 | 30–153 |
| MATH grade 5 | 993 | 109.31 | 13.54 | 37–156 |
| MATH age 15 | 887 | 102.92 | 14.22 | 48–168 |

*Note*. MCI = mother–child interaction score; CCI = caregiver–child interaction score; VOC = Woodcock-Johnson Picture Vocabulary score; MATH = Woodcock-Johnson Applied Problems score.

**Vocabulary.** Vocabulary skills were assessed using the Picture Vocabulary subtest from the Woodcock-Johnson Psycho-Educational Battery-Revised (WJ-R; McGrew, Werder, & Woodcock, 1991; Woodcock & Johnson, 1989) at 4.5 years, first grade, third grade, fifth grade, and age 15 years. The subtest measures both receptive and expressive vocabulary and is reliable and valid for the age ranges used in the current study (McGrew et al., 1991). The standardized achievement scores were used at each wave, thus a mean score of 100 and standard deviation of 15 were expected in a normative sample, which were close to the observed values in the study sample (see Table 2).

**Mathematics.** Mathematics achievement was assessed using the Applied Problems subtest from the Woodcock Johnson Tests of Achievement (McGrew et al., 1991; Woodcock & Johnson, 1989), which was individually administered at age 4.5 years, first grade, third grade, fifth grade, and age 15 years. As with the Picture Vocabulary subtest, this instrument is valid and reliable for this age range (McGrew et al., 1991). The subtest assesses children's ability to solve mathematical problems that include basic counting, addition, subtraction, and multiplication primarily through word problems read to the child. The standardized achievement scores were used at each wave, with scores close to the normative sample expected mean of 100 and standard deviation of 15 (see Table 2). For vocabulary and mathematics, we used the standardized achievement scores because we were interested in how early interactions related to overall performance in these domains rather than growth in these areas.

**Child, family, and childcare covariates.** Child, family, and childcare covariates were included in all of the models (see Table 1 for the descriptive statistics on all covariates). Child-level covariates were gender (1 = male, 0 = female) and race/ethnicity (dummy codes for Black, Hispanic, and other with White as the reference group). Mother-level covariates were maternal education (years of completed schooling), maternal age at the 1-month visit, parenting stress measured at the 6-month home visit using the Parenting Stress Index (Abidin, 1983), maternal vocabulary measured at the 36-month visit using the Peabody Picture Vocabulary Test, and maternal self-reports of separation anxiety (Hock, DeMeis, & McBride, 1988), collected at the 6-, 15-, and 24-month visits, maternal depression measured using the Center for Epidemiological Studies Depression Scale (Radloff, 1977) at the 6-, 15-, 24-, and 36-month waves, and maternal health at the 6-, 15-, 24-, and 36-month waves. Additional family level covariates were the mean income-to-needs ratio collected at the 6-, 15-, 24-, and

36-month visits, and the proportion of visits in which there is a father present in the household at the 6-, 15-, 24-, and 36-month waves (1 = father present, 0 = father not present). Childcare covariates included: the mean number of hours in all types of child care at the 6-, 15-, 24-, and 36-month waves, and the primary type of child care across the 6-, 15-, 24-, and 36-month waves (i.e., grandparent, child care home, or center-based care).

To simplify our statistical models and form more reliable measurement, when child, family, and childcare covariates existed at multiple waves across the first 3 years, we used the average of all waves. For example, this was done to control for overall levels of family income, rather than to control for family income at 6-, 15-, 24-, and 36-month waves specifically. However, for hours in childcare, we controlled for each specific wave because of its close relation to the independent variable of interest: caregiver–child interactions. More information on all the child, family, and childcare covariates are available in the SECCYD technical manuals that are available at https://www.icpsr.umich.edu/icpsrweb/ICPSR/series/00233.

## Analytic Plan

To address the research questions of additive and synergistic relations between stimulating–responsive mother–child and caregiver–child interactions during the first 3 years and children's vocabulary and mathematics achievement from age 4.5 to 15 years, a structural equation modeling approach is utilized. Two latent variables for early interactions are considered: stimulating–responsive mother–child interactions measured at four time points during the first 3 years of life (i.e., 6, 15, 24, and 36 months) and stimulating–responsive caregiver–child interactions measured at four time points during the first 3 years (i.e., 6, 15, 24, and 36 months). Two latent variables for child outcomes are also examined: child vocabulary measured at five time points from age 4.5 to 15 years and child mathematics achievement measured at five time points from age 4.5 to 15 years. A latent variable interaction was added to the models to test whether mother–child and caregiver–child stimulating–responsive interactions have synergistic relations on later vocabulary and mathematics.

The structural equation modeling framework has the advantage of modeling the shared variance among observed indicator variables for the constructs (i.e., no measurement error in the latent variables). Another advantage of this approach is full information maximum likelihood estimation (FIML), which allows the use of all available data to inform the model estimates, including control variables.

In addition to using latent variables to examine overall associations between stimulating–responsive mother–child and caregiver–child interactions on children's vocabulary and mathematics achievement from age 4.5 to 15 years, we conduct additional analyses to determine if effects associated with mother–child and caregiver–child interactions are different at specific time points (e.g., at 4.5 years, but not later, or up to Grade 5, but not later). We elected to use this approach rather than linear or piecewise linear growth curve models to best address our specific research question of whether associations remain stable, become weaker with time, or are related sporadically. Importantly, these models were not constrained in any way that would force associations between the mother–child or caregiver–child interactions and later mathematics and vocabulary outcomes to change in a parametric way across time. This allows for the associations for the first 3 years to be assessed in terms of "persistence" versus "fade-out" regarding magnitude of estimates that are not restricted. Analyses that specify linear growth curve models and piecewise linear growth curve models for the outcomes are available by request from the first author.

In a final set of models, we add the age 4.5 year mother–child and caregiver–child interaction variables to examine if they explain additional variance in the outcomes above and beyond the first 3 years alone, and if the statistical significance for the first 3 years variables are altered once the age 4.5 year variables are included.

All descriptive analyses and data management were conducted using Stata 14 (StataCorp, 2015), and all structural equation modeling was done using Mplus 8 (Muthén & Muthén, 1998–2017). The maximum likelihood estimator with robust standard errors was used to deal with non-normality and nonindependence of observations (Muthén & Muthén, 1998–2017). This provides more conservative estimations of statistical significance by providing a correction to standard errors due to non-normality of distribution. Additionally, the cluster option was used to indicate that observations came from 10 research sites, such that observations within site were not independent, and therefore standard errors were adjusted.

Tables 1 and 2 provide the number of observations for each measure (for a correlation matrix of all study variables, see Table S1 in the online supplemental materials). All models used a FIML approach to deal with missing data. Given the longitudinal nature of the study design (i.e., children followed from birth through age 15), some participants were lost to attrition. Specifically, missing data ranged from 22.29% at 54 months to 34.60% at age 15 years on the outcomes, though only 15.25% of participants provided no outcome data (of the original 1,364 sample). In other words, outcome data were provided by 1,156 of the 1,364 total participants included in analyses. In Table S2 in the online supplemental materials, we examine all covariates as predictors of whether children were missing data from the study at each wave for the outcomes (54 months to age 15; columns 1 through 5) and if children did not have any outcome data (column 6). Only two covariates were strongly related to providing no outcome data (i.e., $ps < .001$), such that children were less likely to have any outcome data if they had younger, less educated mothers. However, because FIML uses covariates to inform model estimates, we consider the missing at random a reasonable assumption and a better alternative to listwise deletion. That is, the FIML approach reduces bias associated with missing data for any reason by using all the available information to provide the most likely model estimates (Acock, 2012). FIML typically performs similar to multiple imputation approaches and outperforms model estimates using listwise deletion (Acock, 2005).

# Results

## Measurement Models

Analyses followed a sequence of three steps, with additional models provided in the online supplemental materials. First, a confirmatory factor analysis approach was used to model latent

Table 3
*Key Fit Statistics From Measurement Models*

| Models | *n* | $\chi^2(df)$ | CFI | RMSEA | SRMR | T1 λ | T2 λ | T3 λ | T4 λ | T5 λ |
|---|---|---|---|---|---|---|---|---|---|---|
| MCI[a] | 1,306 | 17.85 (2)*** | .99 | .08 | .02 | .60 | .66 | .64 | .75 | |
| CCI[a] | 848 | 19.21 (2)*** | .94 | .10 | .04 | .41 | .63 | .80 | .60 | |
| VOC[b] | 1,156 | 83.40 (5)*** | .98 | .12 | .02 | .73 | .82 | .88 | .90 | .88 |
| MATH[b] | 1,155 | 59.52 (5)*** | .98 | .10 | .02 | .71 | .84 | .85 | .88 | .80 |
| Full model | 1,313 | 556.46 (129)*** | .95 | .05 | .05 | | | | | |

*Note*. Full model includes mother–child interaction score (MCI), CCI (caregiver–child interaction score), Woodcock-Johnson Picture Vocabulary score (VOC), and Woodcock-Johnson Applied Problems score (MATH) in a single analysis with all latent variables correlated. CFI = comparative fit index; RMSEA = root mean square error of approximation; SRMR = standardized root mean square residual.
[a] For MCI and CCI, Time 1 (T1) is 6 months, Time 2 (T2) is 15 months, Time 3 (T3) is 24 months, and Time 4 (T4) is 36 months. [b] For VOC and MATH, T1 is 54 months, T2 is Grade 1, T3 is Grade 3, T4 is Grade 5, and T5 is age 15.
*** $p < .001$.



factor variables for mother–child stimulating–responsive interactions, caregiver–child stimulating–responsive interactions, vocabulary, and mathematics to examine measurement model fit indices prior to the inclusion of covariates (see Table 3). All models statistically fit well in terms of their comparative fit index (CFI) and standardized root mean square residual (SRMR; Kline, 2005). As expected, the models with fewer degrees of freedom had poorer fit in terms of their root mean square error of approximation (RMSEA; Kenny, Kaniskan, & McCoach, 2015), however, the full measurement model had a relatively well-fitting RMSEA (Kline, 2005). All loadings on the latent factors were of satisfactory level (only one loading fell below .60, i.e., caregiver–child interaction at 6 months), suggesting each wave of measurement shared substantial variance with the underlying construct. All loadings for vocabulary and mathematics were especially large, which is evidence of relatively substantial shared variance in performance over time in these skills (loadings ranged from .71 to .90).

In the full measurement model, mother–child and caregiver-interactions were correlated ($r = .36$, $p < .001$). This suggests that children who have more stimulating–responsive interactions with mothers have more stimulating–responsive interactions with caregivers on average (and vice versa). However, it also suggests these are separable constructs that are not tapping the same construct, which could be the case if both types of interactions were strongly driven by the child as opposed to the mother or caregiver. In summary, the measurement models are statistically consistent with the theoretical conceptualization that there are underlying latent factors that account for stimulating–responsive mother–child interactions and stimulating–responsive caregiver–child interactions from child age 6 to 36 months and underlying latent factors that account for vocabulary and mathematics scores from child age 4.5 to 15 years.

## Additive Associations of Stimulating–Responsive Interactions With Mothers and Caregivers on Later Vocabulary and Mathematics

Once the measurement models were established to be well-fitting, a structural equation model was run to estimate associations between stimulating–responsive mother–child interactions and stimulating–responsive caregiver–child interactions during the first 3 years of life on children's vocabulary and mathematics achievement between 4.5 and 15 years (see Figure 1; $\chi^2[409] = 1013.47$, $p < .001$; RMSEA = .03; CFI = .95; SRMR = .03; Bayesian information criterion [BIC] = 201898). This model included the child, family, and childcare covariates and estimated the associations for latent factors of stimulating–responsive mother–child interactions and stimulating–responsive caregiver–child interactions predicting latent factors of vocabulary and mathematics achievement between 4.5 and 15 years.

Stimulating–responsive mother–child interactions during the first 3 years had significant positive associations with children's later vocabulary ($\beta = .20$, $p < .001$) and mathematics achievement ($\beta = .26$, $p < .001$), and stimulating–responsive caregiver–child interactions had a significant positive association with mathematics ($\beta = .11$, $p = .045$). To interpret the standardized effects specifically, the model estimates for a standard deviation increase in stimulating–responsive interaction with mothers during the first 3 years, the predicted standard deviation increase for vocabulary was .20 and for mathematics was .26. For a standard deviation increase in caregiver–child interactions during the first 3 years, the predicted standard deviation increase for mathematics achievement was .11. See Table S3 in the online supplemental materials for the estimates of the covariates.

**Persistence versus fadeout of associations.** A series of additional models were tested because of the assumptions the primary analyses made for how mother–child interactions and caregiver–child interactions relate to later vocabulary and mathematics. First, we estimated models that included specific paths between latent mother–child interactions and caregiver–child interactions for each specific wave of vocabulary and mathematics at age 4.5 years, first grade, third grade, fifth grade, and age 15 years, rather than modeled on the overall latent factors of vocabulary and mathematics. This was done to check if stimulating–responsive mother–child interactions and caregiver–child interactions during the first 3 years had substantially different effects on child outcomes at different child ages (e.g., if the associations faded over time).

In general, the associations between stimulating–responsive mother–child interactions and caregiver–child interactions during the first 3 years and subsequent vocabulary and mathematics skills indicated persistent associations that did not diminish as quickly as would be predicted from a purely autoregressive standpoint of early skills influencing later skills (see Figure 2). Although the largest associations were typically observed at 4.5 years, other

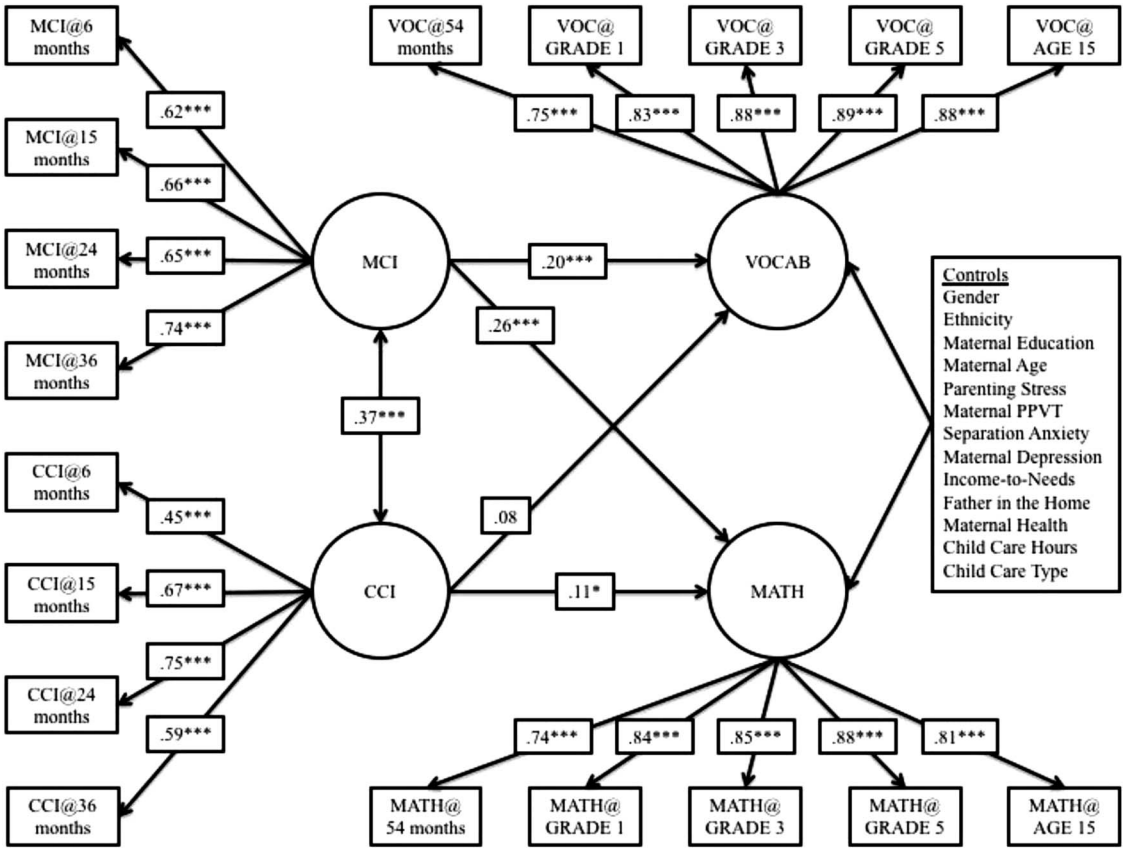


*Figure 1.* Associations between early mother–child and caregiver–child interactions and children's later vocabulary and mathematics skills. Standard errors were adjusted based on site location. MCI = mother–child interaction score; CCI = caregiver–child interaction score; VOC = Woodcock-Johnson Picture Vocabulary score; MATH = Woodcock-Johnson Applied Problems score. * $p < .05$. *** $p < .001$.

associations were equivalent at later ages. For example, associations between stimulating–responsive interactions with mothers and child vocabulary were similar at age 4.5 years and first grade, and similar at third grade and fifth grade. For mathematics, associations were larger at age 15 than fifth grade. Stimulating–responsive caregiver–child interactions were more highly associated with mathematics skills at third grade than first grade.

**Including age 4.5 stimulating–responsive interactions.** Second, models were tested in which we included measures of stimulating–responsive mother–child and caregiver–child interactions at 4.5 years. This was done to test if the mother–child and caregiver–child interaction variables at the 4.5-year wave explained additional variation in the outcomes beyond the first 3 years. The pattern of significant results was unchanged for the birth through three variables, though stimulating–responsive mother–child interactions at child age 4.5 years was also significantly associated with mathematics achievement. All other associations for the 4.5-year variables were nonsignificant.

**Sensitivity checks.** Two additional models were run to examine whether using latent variables to model mother–child interactions and caregiver–child interactions influenced the estimates. The observed pattern of significant associations was unaffected when only examining mother–child interactions at 36 months and caregiver–child interactions at 24 months (the largest loading indicator variables for each construct; see Figure S1 in the online supplemental materials). Additionally, when examining average mother–child interactions and caregiver–child interactions over the first 3 years, the effect was no longer significant between average caregiver–child interactions and mathematics (see Figure S2 in the online supplemental materials).

## Synergistic Associations of Mother–Child and Caregiver–Child Interactions

Next, we examined if effects associated with early mother–child interaction and later outcomes were moderated by early caregiver–child interaction. To address this question, a statistical interaction between the latent mother–child interactions and latent caregiver–child interactions was added to the model. The statistical interaction between stimulating–responsive experiences with mothers and caregivers on children's mathematics achievement was statistically significant ($\beta = -.18$, $p = .007$; see Figure 3; BIC = 201894; and see Table S4 in the online supplemental materials for the estimates of child, family, and childcare covariates). The gray lines in Figure 3 represent the main effects in the model, but they should be

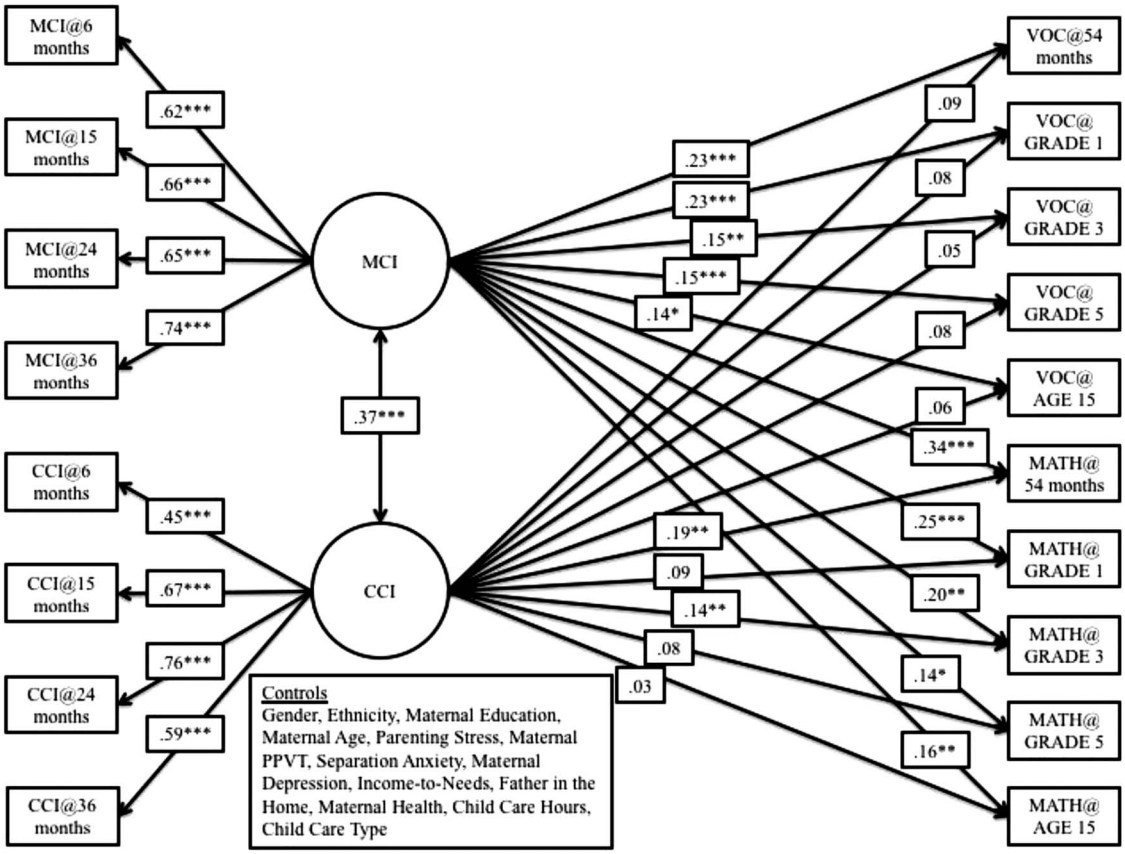


*Figure 2.* Associations between early mother–child and caregiver–child interactions and later vocabulary and mathematics at each wave. Standard errors were adjusted based on site location. MCI = mother–child interaction; CCI = caregiver–child interaction; VOC = Woodcock-Johnson Picture Vocabulary score; MATH = Woodcock-Johnson Applied Problems score. $^{*}$ $p < .05$. $^{**}$ $p < .01$. $^{***}$ $p < .001$.

interpreted within the context of the statistical interaction effect in the model.

To aid interpretation of this synergistic effect, a graph showing the predicted effect on standard deviation changes from average mother–child interactions and caregiver–child interactions on mathematics are shown for four hypothetical groups: (a) low (i.e., −1 standard deviation) maternal stimulation and low caregiver stimulation, (b) high (i.e., +1 standard deviation) maternal stimulation and low caregiver stimulation, (c) low maternal stimulation and high caregiver stimulation, and (d) high maternal stimulation and high caregiver stimulation (see Figure 4). Children low on both maternal and caregiver stimulating–responsive interactions performed substantially worse (.61 standard deviations) than children average on mother–child interactions and caregiver–child interactions (i.e., the *x*-axis in Figure 4), respectively. The statistical interaction between maternal and caregiver responsiveness-stimulation on children's vocabulary was not significant (see Figure 3), although the main effect of caregiver responsiveness-stimulation on vocabulary did become statistically significant in the model that included the statistical interaction.

## Persistence Versus Fadeout of Synergistic Associations

Next, we examined the synergistic effects of maternal and caregiver stimulating–responsive interactions on each time period (age 4.5 years, Grade 1, Grade 3, Grade 5, age 15 years) separately. For both vocabulary and mathematics, the synergistic associations between stimulating–responsive interactions with mother and caregiver were most negative for Grade 3 and Grade 5 when examining the outcomes at each wave (see Figure S3 in the online supplemental materials). Thus, although there was some evidence of a diminishing effect when examining the additive effects, there was no such evidence with the interaction term.

## Post Hoc Analyses: Does Excluding Maternal Vocabulary Alter Results?

After we found stronger associations with children's later mathematics skills than vocabulary skills, we examined if our pattern of estimates would change if maternal vocabulary was excluded as a control variable. For the first model with additive effects only, the main effects on mathematics remained larger than the main effects on vocabulary, consistent with the model that included maternal vocabulary. For the second model with the synergistic effect, the main effect for mother–child interactions did become larger for vocabulary than the main effect for mother–child interactions predicting mathematics (though this model included a statistically significant interaction term making it challenging to interpret the main effect). In general, the pattern of results remained substan-

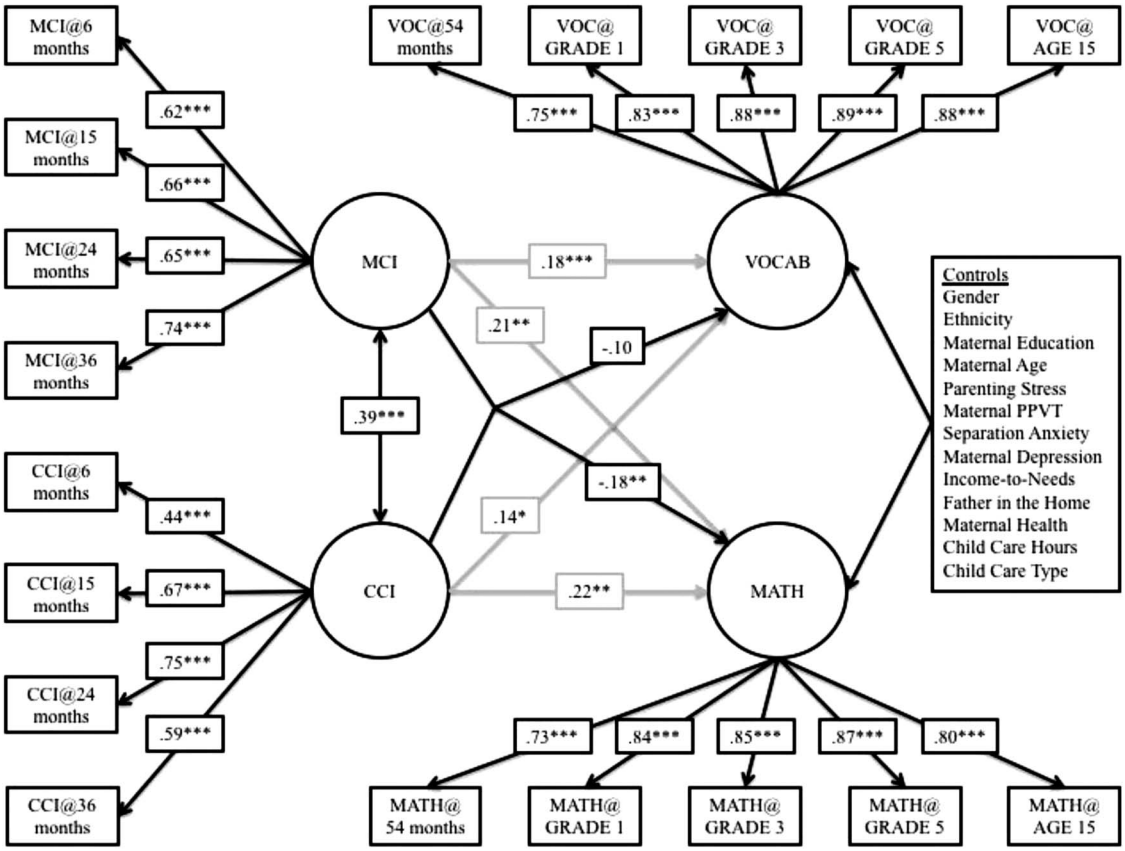


*Figure 3.* The moderation of associations between early mother–child and caregiver–child interactions and later competencies. Standard errors were adjusted based on site location. Gray lines represent main effects in the model; however, these should be interpreted within the context of the interaction effects. MCI = mother–child interaction score; CCI = caregiver–child interaction score; VOC = Woodcock-Johnson Picture Vocabulary score; MATH = Woodcock-Johnson Applied Problems score. $^{*}$ $p < .05$. $^{**}$ $p < .01$. $^{***}$ $p < .001$.

tively similar across both specification and are available by request from the first author.

## Discussion

The current study examines the extent to which stimulating–responsive interactions with mothers and nonparental caregivers during the first 3 years of life are associated with children's later vocabulary and mathematics achievement. A structural equation modeling approach was used to test both additive and synergistic relations between early mother–child and caregiver–child interactions and children's later skills. More stimulating–responsive interactions with both mothers and with caregivers were associated with higher mathematics achievement. More stimulating–responsive interactions with mothers during the first 3 years were associated with children's larger vocabularies through age 15 years.

Our findings extend prior research that has examined children's experiences during the first 3 years of life as setting the stage for later development. Prior work has identified early maternal sensitivity as having enduring associations with social outcomes through adolescence (Fraley et al., 2013) and into adulthood (Raby et al., 2015). Importantly, our findings suggest significant associations of early mother–child interactions are maintained controlling for caregiver–child interactions, as well as a host of child, mother, and family covariates, including maternal vocabulary.

The caregiver–child interactions aspect of the study fits within broader work on the role of early childhood education for long-run cognitive and language outcomes. A contribution of the current study is connecting the specific behavioral frequency ratings observed during the first 3 years of life with these outcomes. For instance, these behavioral frequency codes were associated with child outcomes at ages 3 (NICHD ECCRN, 2000b) and 4.5 years (NICHD ECCRN, 2003), but this is the first study to our knowledge that examined associations between the frequency counts of stimulating–responsive caregiver behaviors and much later skills. Behavioral codes for stimulating–responsive interactions with caregivers may be an important tool for practitioners and policymakers interested in understanding early childhood education quality. Unlike broad, global assessments, these measures are easier to code and use by practitioners (NICHD ECCRN, 2001; Pellegrini, 2004). They also provide an easy to interpret description of the specific experiences of individual children in the classroom.

In addition to additive relations in which both mother–child and caregiver–child interactions were related to later mathematics achievement, we found a moderated relation that was consistent

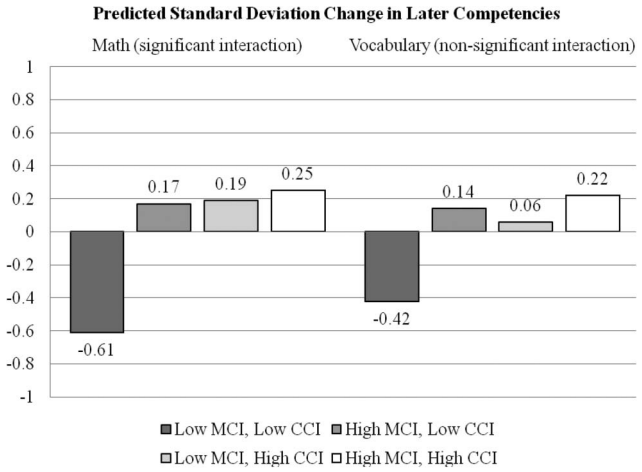


*Figure 4.* Predicted standardized effects for later competencies based on hypothetical groups of mother–child interaction score (MCI) and caregiver–child interaction score (CCI). The values are calculated based on standardized results (i.e., including the interaction). Low is one standard deviation below the mean, and high is one standard deviation above the mean. VOC = Woodcock-Johnson Picture Vocabulary score; MATH = Woodcock-Johnson Applied Problems score.

with the dual-risk hypothesis. Specifically, children who had few stimulating–responsive interactions with their mothers and with their caregivers had substantially worse mathematics achievement. These findings are consistent with the work of Nelson and colleagues (2007) who found that very low levels of stimulating–responsive interactions during the first 3 years were exacerbated when interventions were not put into place to provide supplementary enriching care experiences.

Another question motivating the current study was whether the associations between early mother–child and caregiver child interactions with mathematics and vocabulary outcomes faded over time. Evidence consistent with some fadeout but also persistence was found. Relations between stimulating–responsive interactions in the first 3 years and children's vocabulary and mathematics achievement were higher at 4.5 years than at later ages, but relations between these early stimulating–responsive interactions and later functioning continued to be significant through age 15 years. Indeed, there were instances of larger associations between mother–child and caregiver–child interactions at later ages than earlier waves.

In general, the associations between stimulating–responsive interactions during the first 3 years and later outcomes were larger for mathematics than vocabulary. This was unanticipated because we had expected that early stimulating experiences, which were generally focused on language, would be more important for later vocabulary. Additionally, the smaller effects found between early interactions and vocabulary were not explained by removing maternal vocabulary as a control variable.

Follow-up analyses examined if the inclusion of children's experiences in the later preschool period at age 4.5 years accounted for later vocabulary or mathematics achievement. The inclusion of the later mother–child and caregiver–child experiences at 4.5 years did not alter the significant associations between experiences in the first 3 years and later outcomes, providing support for the importance of the very early experiences with respect to later vocabulary and mathematics. At the same time, stimulating–responsive interactions with mothers at 4.5 years did predict later mathematics above and beyond the earlier experiences of children. Taken together, these findings suggest the importance of children's experiences during the first 3 years for later vocabulary and mathematics, with later experiences also potentially playing a role.

## Potential Implications for Early Childhood Interventions and Policies

The findings from this large study of normative development are consistent with early childhood intervention studies (e.g., Campbell et al., 2001) and neuroscience research (Grantham-McGregor et al., 2007; Nelson, Fox, & Zeanah, 2014) that focused on low-income and at-risk samples. In particular, the findings underscore the potential value of stimulating–responsive interactions with mothers during the first 3 years of life for children's later vocabulary and mathematics achievement, as well the independent value of stimulating–responsive interactions with caregivers during the first 3 years in relation to mathematics achievement. These findings suggest that interventions aimed at both mothers and caregivers could have additive effects on children's skills. Interventions would ideally seek to boost the quality of interactions with both mothers and caregivers. The current study also identifies a group of children who were at the highest risk for lower mathematics achievement: The negative effects associated with a dearth of stimulating–responsive mother–child interactions were exacerbated and magnified when children also lacked stimulating–responsive interactions with caregivers. In circumstances in which intervening with mothers is not feasible, providing high-quality experiences with caregivers may be particularly important.

The current findings also highlight the need to consider the timing of early childhood interventions. Although many contemporary interventions are focused on prekindergarten programs serving 4-year-old children and 5-year-old children, the current study identifies the potential importance of the first 3 years for the development of vocabulary and mathematics skills. The possible long-run effects on cognitive and language outcomes may be amplified by starting earlier and by targeting the quality of interactions with mothers and/or caregivers.

## Limitations and Future Directions

Several study limitations must be noted. First, in this nonexperimental study, issues of child effects and omitted variable bias may account for the obtained findings. Children who had more advanced language and social skills may have elicited more and better responsive and stimulating interactions with their mothers and nonparental caregivers. Future research would benefit from exploring potential bidirectional relations among children's early skills and responsive–stimulating interactions with mothers and nonparental caregivers. The associations found in this study also may be due to unobserved characteristics of the children, parents or caregivers that led to higher quality mother–child and caregiver–child interactions. Furthermore, the stronger associations found for mathematics achievement compared to later vocabulary may reflect the fact that our measures of early

stimulating–responsive interactions did not directly measure the conversational turn-taking that has been closely associated with later language outcomes (Gilkerson et al., 2018; Romeo et al., 2018).

A potential limitation with comparing the estimates between mother–child and caregiver–child interactions is that the measures were assessed in different ways. The mother–child interactions involved short semistructured play situation with observers, whereas the caregiver–child interactions were observed for longer periods and in the natural setting. Thus, although standardized estimates are presented to eliminate differences due to raw scaling, differences in how the measures were collected could contribute to the magnitudes of the observed associations and conclusions should not be drawn about which type of interaction is more important. Additionally, children's childcare experiences probably change considerably during the first 3 years and we placed our focus on overall levels rather than this variability. Future research could better inform issues related to specific timing of experiences and to what extent within-child variability in caregiver–child interactions relate to developmental outcomes. Furthermore, we did not have item level data for our outcomes to assess longitudinal invariance of the measures, thus our findings could be influenced by measurement characteristics that change over time. Finally, although we included many child, family, and child care covariates, it will be important for future research to explore additional confounds, with the strongest evidence being findings from experimental studies.

## Conclusions

This study finds evidence for both additive and synergistic associations between mother–child and caregiver–child interactions during the first 3 years and children's mathematics achievement and vocabulary from early childhood through adolescence. More stimulating–responsive interactions with mothers were associated with higher mathematics and vocabulary achievement, with statistically significant associations persisting through age 15 years. More stimulating–responsive interactions with caregiver also predicted children's later mathematics. Consistent with a dual-risk hypothesis, children who received little stimulation from both their mothers and caregivers during the first 3 years were at heightened risk for poorer mathematics achievement. Taken together, these finding underscore the potential importance of children's experiences in the first 3 years in helping to address academic achievement gaps.

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