Received: 11 July 2022 | Revised: 5 December 2022 | Accepted: 13 March 2023

DOI: 10.1111/desc.13396

RESEARCH ARTICLE

Developmental Science WILEY

From terrible twos to sassy sixes: The development of vocabulary and executive functioning across early childhood

Madeleine Bruce[1] | Jyoti Savla[2] | Martha Ann Bell[1]

[1]Virginia Tech, Department of Psychology, Blacksburg, Virginia, USA

[2]Virginia Tech, Department of Human Development & Family Science, Blacksburg, Virginia, USA

Correspondence
Madeleine Bruce, Virginia Tech, Department of Psychology, at 890 Drillfield Dr., Blacksburg, VA 24060, USA.
Email: madeleine.bruce@utah.edu

Funding information
Eunice Kennedy Shriver National Institute of Child Health and Human Development, Grant/Award Number: R01 HD049878

Abstract

Across the early childhood period of development, young children exhibit considerable growth in their executive functioning (EF) and vocabulary abilities. Understanding the developmental trajectory of these seemingly interrelated processes is important as both early vocabulary and EF have been shown to predict critical academic and socio-emotional outcomes later in childhood. Although previous research suggests that EF and vocabulary are correlated in early childhood, much of the existing longitudinal research has focused on unidirectional relations among preschool child samples. The current large-scale study, therefore, sought to examine whether children's vocabulary and EF abilities are bidirectionally related over time across four measurement waves in early childhood (i.e., at ages 2, 3, 4, and 6). At each timepoint, children's vocabulary skills were positively correlated with their concurrent EF abilities. After controlling for child sex and maternal education status, the best-fitting, cross-lagged panel model was a unidirectional model whereby children's early vocabulary scores predicted their later EF performance at each timepoint. Although age 2 EF significantly predicted age 3 vocabulary size, this association was no longer significant after accounting for maternal education status. Our results illustrate that vocabulary size plays an important role in predicting children's later EF performance across various timepoints in early childhood, even after controlling for children's initial EF scores. These findings have important implications for intervention research as fostering early vocabulary acquisition may serve as a possible avenue for improving EF outcomes in young children.

KEYWORDS

cross-lagged panel model, development, early childhood, executive functions, longitudinal, vocabulary

Research Highlights

- Children's vocabulary size is positively correlated with their concurrent executive functioning skill at ages 2, 3, 4, and 6

- Young children's early vocabulary scores predict their later EF performance across measurement waves, even after controlling for initial EF skill
- There is stability in children's relative vocabulary size and executive functioning performance over time in early childhood

1 | INTRODUCTION

Early childhood represents a period of extensive growth in both vocabulary and executive functioning (EF) development. Across the first few postnatal years, advancements in children's word comprehension and production abilities (i.e., vocabulary; Fenson et al., 1994) are accompanied by maturation in the cognitive processes that enable self-directed and goal-oriented behavior (i.e., EF; Diamond, 2013). Indeed, these early emerging skills lay the groundwork for important developmental outcomes later in childhood, such as academic success and social competence (Alduncin et al., 2014; Blair & Razza, 2007; Longobardi et al., 2016; Moll et al., 2015). For instance, Moll et al.'s (2015) longitudinal study illustrates that both preschool verbal ability and EF predicted children's oral number skills the following year, which in turn predicted their arithmetic abilities during the elementary school years. Developmental research further suggests that children's vocabulary and EF skills are closely related in early childhood, as children with larger vocabularies frequently exhibit greater EF skills (Gathercole & Baddeley, 1989; Kuhn et al., 2014; Willoughby et al., 2017). Understanding the developmental trajectory of these foundational and interrelated processes may therefore assist in the identification of early warning signs and inform related intervention efforts in early childhood. Thus, our study sought to evaluate the longitudinal associations between EF and vocabulary across multiple timepoints during the early childhood years.

1.1 | The early development of vocabulary and EF

Both language and EF can be thought of as multifaceted constructs that consist of distinct yet interrelated subcomponents, which can be differentially employed based on the task at hand. Below, we address the individual developmental trajectories of both vocabulary and EF starting in infancy and extending across the early childhood period.

1.1.1 | Vocabulary development

Bloom and Lahey's (1978) language taxonomy identifies three separate domains: content (i.e., vocabulary), form (i.e., grammar), and use (i.e., pragmatics). These individual domains frequently intersect to allow children to understand and/or produce speech in a manner that is both structurally and contextually appropriate. Nonetheless, the "content" domain and more specifically, vocabulary acquisition, is of particular interest to early childhood researchers. This is not only because word knowledge emerges in infancy and develops across early childhood (Fenson et al., 1994), but also because vocabulary appears to play a central role in children's ability to mentally represent complex problems and regulate their thoughts and behaviors (Vygotsky, 1978; Zelazo et al., 2003; 2006).

Vocabulary development is heavily influenced by repeated exposure to speech during interactions with a social partner (Hart & Risley, 1995; Huttenlocher et al., 1991; Kuhl, 2007). Indeed, even newborns show a strong preference for listening to speech over complex non-speech sounds (Vouloumanos & Werker, 2004), and prelinguistic infants' language processing skills are predictive of their vocabulary outcomes in toddlerhood (Newman et al., 2016). By the end of the first postnatal year, typically-developing children have obtained sophisticated speech perception skills and may have started to produce linguistically-meaningful vocalizations (Fenson et al., 1994; Oller, 1980; Polka & Werker, 1994; Werker & Tees, 2002). Although considerable variability has been reported in the literature, children have an average vocabulary size of approximately 50 words by 18-months of age (Shipley & McAfee, 2015). From there, vocabulary growth is extensive and continues across the early childhood period, as the average number of words that children understand at age 3 and age 6 is estimated at ∼1,000 and ∼10,000 words, respectively (Anglin, 1993; Shipley & McAfee, 2015). Developmental researchers report that nouns tend to dominate much of children's early vocabularies (Alcock, 2017; Bates et al., 1994). It has been proposed that this early "noun bias" reflects the relative ease of extracting observable and temporally-stable noun-referent combinations in comparison to other word forms, such as verbs or prepositions (Gentner, 1982). However, alternative theories regarding this trend point to the structural properties of various languages (e.g., the tendency of English speakers to place nouns at the end of a sentence) or the methodology used to collect vocabulary data (Tardif et al., 1997; 1999). Although even 2.5-year-olds' more readily acquire object-noun pairs in comparison to verb-action pairs (Childers & Tomasello, 2002), this noun-verb gap diminishes over the course of development as vocabulary size increases and children begin using language in increasingly sophisticated ways.

1.1.2 | EF development

EF refers to a series of top-down cognitive processes (i.e., inhibitory control, cognitive flexibility, working memory) that facilitate effortful and goal-directed actions such as planning, problem-solving, and modulating one's behavior (Bell & Garcia-Meza, 2020; Diamond, 2013). Developmental research illustrates that EF is best represented as a unitary construct during the early childhood period (Garon et al., 2008; Wiebe et al., 2008; 2011). Diamond (2013) further argues that inhibitory control and working memory in particular are closely related and often operate alongside one another when completing tasks. EF emerges in late infancy and undergoes significant development across the toddler, preschool, and early school years as a result of maturational changes to the prefrontal cortex (Carlson et al., 2005; Diamond, 2002; Fiske & Holmboe, 2019). EF is of particular interest to early childhood researchers because in addition to predicting a host of socio-emotional and academic outcomes (Blair & Razza, 2007; Espy et al., 2004), EF skills may enable children to detect and focus on linguistic information present in their environment in the pursuit of vocabulary acquisition (Blankson et al., 2011; Kapa & Colombo, 2014).

Much of the infant EF literature has focused on children's performance on the A-not-B task due to the limited number of EF tasks that are developmentally-appropriate at this age (Bell, 2012; Diamond et al., 1997). On this Piagetian task, infants must hold information in the mind as to where a desirable object has been hidden and inhibit the urge to incorrectly search for the object in a familiar location. Around 8-months of age, typically-developing infants are able to successfully locate the object in a new location, and longer delays between hiding/searching are required to produce retrieval errors with older infants and toddlers (Bell et al., 2022; Espy et al., 1999). By the second postnatal year, however, a wide variety of EF tasks are available to researchers as a result of significant advancements in children's early motor and verbal skills. Across the toddler and preschool years, rapid improvements have been reported in children's performance on conflict/delay inhibitory tasks (Carlson et al., 2005; Joyce et al., 2016), multilocation search tasks (Diamond et al., 1997; Wiebe et al., 2010), and working memory-focused tasks (e.g., spinning/stationary pots; Diamond et al., 1997; Wiebe et al., 2010). Despite the integrative nature of EF in early childhood, developmental researchers have reported that improvements in children's cognitive flexibility skills are observed slightly later in early childhood, perhaps because they build upon early working memory and inhibitory control abilities (Blakey et al., 2016; Diamond, 2013). For instance, kindergarteners are more adept at switching between conflicting task rules on the Dimensional Change Card Sort (DCCS) Task in comparison to toddlers and even preschoolers (Diamond, 2013).

1.2 | The longitudinal link between vocabulary and EF

Beyond similarities between the individual developmental trajectories of EF and vocabulary, there is good reason to postulate that these processes may be interrelated based on existing theory and empirical research. From a Vygotskian perspective, self-directed speech allows children to monitor and adjust their own thoughts or actions (Vygotsky, 1962; 1978). Indeed, research indicates that preschoolers who produce more task-relevant, self-directed vocalizations score higher on tasks that require EF and self-regulatory skills (Azmitia, 1992; Behrend et al., 1989; Mulvihill et al., 2021). On the other hand, inhibitory control/attentional shifting may enable children to better focus on novel word-referent pairs, while working memory abilities may be needed to organize and produce communicative messages (Blankson et al., 2011; Gathercole & Baddeley, 1989; Kapa & Colombo, 2014; Netelenbos et al., 2018). As an example, Kapa and Colombo (2014) illustrate that preschool children's EF skills predicted their success in acquiring new words when presented with an artificial language learning task. Taken together, vocabulary may play a role in the successful execution of effortful and goal-oriented actions, while children's emerging EF abilities may promote early word learning and production.

Developmental researchers frequently report that children's vocabulary and EF skills are positively correlated in early childhood (Carlson et al., 2005; Harvey & Miller, 2017; Kraybill et al., 2019; Wolfe & Bell, 2004). That is, children with strong verbal skills consistently outperform their peers with smaller vocabularies on a wide variety of EF tasks. Some longitudinal studies even show that children's initial skills in one domain (e.g., vocabulary) predict their later outcomes in the other (e.g., EF; Fuhs et al., 2014; Kuhn et al., 2014; Schmitt et al., 2019; Willoughby et al., 2017). For example, Schmitt et al. (2019) demonstrate that 4-year-olds' EF and vocabulary skills at the start of the preschool year were predictive of their respective abilities at the end of the academic year. This finding suggests that individual differences in these foundational skills during the school-age years may be influenced by their preceding EF and vocabulary abilities measured earlier in development.

The finding that various aspects of cognitive development are positively correlated is well-documented even outside the early childhood literature (van der Maas et al., 2006), which indicates that there are reinforcing interactions between processes throughout development. Even so, there is considerable disagreement within the longitudinal literature regarding the interdependence of vocabulary and EF across early childhood. For instance, some studies have failed to find evidence of a bidirectional relation between EF and vocabulary (Fuhs & Day, 2011; Petersen et al., 2014; Weiland et al., 2014), while other studies report that neither EF nor vocabulary were predictive of children's respective outcomes (Chung & McBride-Chang, 2011; Gooch et al., 2016). Inconsistency in the research findings observed in the early childhood literature may be due in part to the divergent study designs utilized by researchers (Bruce & Bell, 2022). Indeed, the longitudinal studies discussed above varied in the ages of participants recruited, the number of measurement waves collected, and the EF tasks that were administered. Among the studies that are methodologically comparable, gaps in the literature remain as a result of the field's heavy emphasis on the preschool years; this is despite the empirical evidence showing that both EF and vocabulary have their roots in the first two postnatal years of development (Cuevas & Bell, 2014; Fenson et al., 1994; Miller & Marcovitch, 2015). While a handful of studies have evaluated this association prior to the preschool years, they are nonetheless limited in that they did not examine *bidirectional* relations and/or control for children's initial vocabulary/EF scores (Kuhn et al., 2016; Matte-Gagné & Bernier, 2011; Miller & Marcovitch, 2015; Whedon et al., 2018). To further advance this area of research, our study adopted a structural equation modeling (SEM) approach to investigate the associations between EF and vocabulary across the span of early childhood starting in toddlerhood and continuing into the elementary school years.

1.3 | Current study

Based on the limitations discussed above, additional multi-wave research starting earlier in development and extending into the elementary school years is needed to better clarify the nature of the association between EF and vocabulary development across early childhood. Doing so allows for a more nuanced examination into whether a predictive association exists between EF and vocabulary in early childhood and if so, whether the strength and direction of this longitudinal relation differs as a function of age. The purpose of our study was to examine whether vocabulary and EF are bidirectionally related across four measurement waves using a large community sample of children across early childhood. In the present study, children's vocabulary and EF skills were assessed when they were 2, 3, 4, and 6 years of age using two standardized vocabulary instruments and a battery of empirically established EF tasks. Because multiple studies have reported that children's vocabulary and EF abilities are related over time (see Bruce & Bell, 2022; for an in-depth review of this literature), we hypothesized that a reciprocal association would emerge. As such, the following predictions were made:

Hypothesis 1. *Children's early vocabulary size will predict their later EF performance across all four measurement waves after accounting for children's initial EF scores (e.g., age 3 vocabulary will predict age 4 EF after controlling for age 3 EF).*

Hypothesis 2. *Children's early EF skills will predict their later vocabulary outcomes across all four measurement waves after accounting for children's initial vocabulary size (e.g., age 3 EF will predict age 4 vocabulary after controlling for age 3 vocabulary).*

2 | METHOD

2.1 | Participants

Participants are part of a large-scale longitudinal study that examined emotion regulation and cognitive development. Children were recruited equally from Blacksburg, VA (Virginia Tech) and Greensboro, NC (The University of North Carolina at Greensboro) using mailing lists, media advertisements, flyers, and word of mouth. In this larger longitudinal study, 410 typically-developing, English-speaking children (209 girls, 50.9%) were recruited in infancy and were invited back to the lab at various timepoints in childhood (e.g., at 2, 3, 4,and 6 years of age; see Table 1 for participant demographics). Children were recruited as three cohorts: Blacksburg cohort 1 (n = 106), Blacksburg cohort 2 (n = 105); Greensboro cohort 3 (n = 199). Cohort 1 was recruited first and was approximately 3 years older than cohorts 2 and 3, who were the same age. The number of children who completed a lab visit at each age is as follows: 327 children at age 2, 295 children at age 3, 270 children at age 4, and 194 children at age 6. Details regarding attrition and the sample size at each measurement wave are discussed below.

2.1.1 | Age 2 lab visit

Of the total sample of 410 children that were recruited in early infancy, 83 children did not return for the age 2 lab visit (n_{age_2} = 327; 161 girls). Among the 83 children that did not return for the age 2 lab visit, questionnaire data (i.e., expressive vocabulary data from the MCDI-W&S; see the "Vocabulary Measures" section below) was still mailed in for 20 of these children. No demographic differences were detected between the children who did or did not return for the age 2 visit with respect for child sex, child race, or maternal education (all $ps > 0.05$).

2.1.2 | Age 3 lab visit

Of the 410 children recruited as infants, 115 children did not return for the age 3 lab visit (n_{age_3} = 295; 145 girls). 73 out of these 115 children had not returned to the lab for the age 2 visit either. Starting at age 3, questionnaire-only families were not able to provide any vocabulary or EF data, and these children were therefore coded as missing data at age 3. No demographic differences were detected between children who did or did not return for the age 3 visit with respect to child sex, child race, or maternal education (all $ps > 0.05$). Children who did or did not participate in the age 3 lab visit did not differ in terms of their vocabulary size or individual EF task scores at age 2 (all $ps > 0.05$).

2.1.3 | Age 4 lab visit

Of the 410 children recruited as infants, 140 children did not return for the age 4 lab visit (n_{age_4} = 270; 128 girls). Out of these 140 children, 49 had not returned for both the age 2 and age 3 visit, and an additional 40 children had not returned for only the age 3 visit. No demographic differences were detected between children who did or did not return for the age 4 visit with respect for child sex, child race, or maternal education (all $ps > 0.05$). Children who did or did not participate in the age 4 lab visit did not differ in terms of their age 3 vocabulary size or individual EF task scores (all $ps > 0.05$).

2.1.4 | Age 6 lab visit

Of the 410 children recruited as infants, 216 children did not return for the age 6 lab visit (n_{age_6} = 194; 94 girls). Because of the funding

TABLE 1 Sample demographics at each data collection wave.

	Age 2 (*n* = 347)	Age 3 (*n* = 295)	Age 4 (*n* = 270)	Age 6 (*n* = 194)
Child racial composition				
Asian	1 (0%)	0	0	0
African American/Black	46 (13%)	39 (13%)	38 (14%)	33 (17%)
White	273 (79%)	233 (79%)	210 (78%)	147 (76%)
Other or multiracial	27 (8%)	23 (8%)	22 (8%)	14 (7%)
Maternal educational attainment				
Did not complete high school	7 (2%)	6 (2%)	4 (1%)	4 (2%)
Completed high school	89 (26%)	72 (24%)	66 (24%)	52 (26%)
Completed technical school	26 (7%)	22 (7%)	20 (7%)	13 (7%)
Completed college	148 (43%)	129 (45%)	114 (43%)	79 (41%)
Completed graduate school	75 (21%)	65 (22%)	64 (24%)	45 (23%)
Did not report	2 (1%)	1 (0%)	2 (1%)	1 (1%)

Note: At ages 3, 4, and 6, the sample size reflects the number of children who completed a lab visit at that age. At age 2, the sample size reflects a combination of the number of children who participated in a lab visit at that age ($n = 327$) and the number of children for whom only questionnaire data (i.e., the MCDI-W&S) was received ($n = 20$).

schedule, the 106 children who were members of cohort 1 were not invited to participate in an age 6 lab visit. Of the remaining 110 children who did not return at age 6, 27 children had not returned for any prior visits (at age 2, 3, or 4), 19 had not returned for both the age 3 and age 4 visit, and 26 had not returned for only the age 4 visit. Among these children, no demographic differences were detected between children who did or did not return for the age 6 visit with respect for child sex, child race, or maternal education (all $ps > 0.05$). Children who participated in the age 6 lab visit did not differ in terms of their vocabulary size or performance on the EF tasks measured at age 4 (all $ps > 0.05$).

2.2 | General procedure

Data were collected at both research locations using identical protocols. Research assistants at both institutions were trained by the Principal Investigator (3rd author). To ensure identical administration was maintained between the research labs, the Blacksburg research team periodically viewed the video recordings collected by the Greensboro research team. Additionally, the Blacksburg team provided reliability coding for the behavioral EF data coded by the Greensboro team.

Upon arrival at the lab, a research assistant greeted families and explained the study and lab procedures. Informed consent was obtained from mothers at each visit and verbal assent was obtained from children. Demographic information was collected in infancy when children were initially recruited to participate in the study. At age 2, families were mailed the parent-report vocabulary measure in advance, which they brought with them to their lab visit. After a brief warm-up period, children completed a variety of EF tasks (at ages 2, 3, 4, and 6) and a behavioral vocabulary assessment (at ages 3, 4, and 6). Each session was recorded for offline behavioral coding and reliability coding. Study procedures for the larger study were approved by the Institutional Review Boards at Virginia Tech and University of North Carolina Greensboro: #05-087 and #06-7257 for Infant Temperament and Cognitive Development; #05-243 and #06-0257 for Psychobiology of Cognitive Development; #12-947 and #13-0183 for Psychobiology of Cognitive Development in Middle Childhood.

2.3 | Vocabulary measures

Children's expressive vocabulary at age 2 was assessed via parent-report using the MacArthur-Bates Communicative Development Inventory: Words and Sentences (MCDI-W&S; Fenson et al., 2007). At ages 3, 4, and 6, children's receptive vocabulary was assessed using the Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 2007). Two different vocabulary assessments were administered in the study because the MCDI-W&S is normed for children between the ages of 16- to 30-months, whereas the PPVT is normed for children who are 30-months or older. Although these measures yield slightly different vocabulary metrics (i.e., expressive vs. receptive), previous research using cross-lagged panel modeling has demonstrated strong auto-regressive paths between these vocabulary measures across the toddler and preschool years, which suggests that these measures are tapping into closely related skills in early childhood (Girard et al., 2014).

2.3.1 | MacArthur-bates communicative development inventory (MCDI-W&S; age 2)

The MacArthur-Bates Communicative Development Inventory: Words & Sentences (MCDI-W&S) evaluates the number of words children produce (i.e., expressive vocabulary) using a 680-word vocabulary checklist that is divided into 22 semantic categories. The MCDI-W&S is one of the most frequently administered assessments of language ability in toddlerhood and it is normed for children ages 16- to 30-months. The MCDI-W&S has established high internal consistency, external validity, and test-retest reliability (Fenson et al., 2007). The variable of interest was toddlers' total expressive vocabulary size, with higher values reflecting a larger expressive vocabulary.

2.3.2 | PPVT (ages 3, 4, and 6)

The peabody picture vocabulary test (PPVT) is a standardized measure that evaluates the number of words children comprehend (i.e., receptive vocabulary), and it is normed for children ages 30-months and older. The PPVT was administered by a research assistant to each child individually. Across all trials, children were shown a set of 4 drawings and instructed to select the drawing that best illustrated the word spoken by a research assistant. The PPVT has established high test-retest reliability and construct validity (Community-University Partnership for the Study of Children, Youth, and Families, 2011). The variable of interest was children's unstandardized vocabulary score, with higher values reflecting a larger receptive vocabulary.

2.4 | EF measures

EF was assessed at ages 2, 3, 4, and 6 using a battery of developmentally-appropriate behavioral tasks. The EF tasks detailed below were selected for the current study because these tasks: (a) are established measures of early childhood EF in the developmental literature and (b) reflect a variety of cognitive processes (i.e., working memory, inhibitory control, and cognitive flexibility) that vary in their non-EF demands (e.g., motor/verbal requirements). Interrater reliability scoring was accomplished on at least 18% of the sample and the percent agreement across all tasks listed below was good to excellent (Intraclass correlation coefficients (ICCs $\geq$ 0.86). Acceptable to excellent convergent validity and test-retest reliability has been reported across a large battery of EF tasks similar to the ones administered in the present study (Beck et al., 2011; Howard & Melhuish, 2017).

2.4.1 | Tongue task (age 2)

The Tongue Task required children to hold a goldfish cracker on their tongue without chewing it for increasingly longer intervals of time (i.e., three trials with delays of 10-, 20-, and 30-seconds; Kochanska et al., 2000). Child performance on each trial was coded as either successful (did not chew cracker) or unsuccessful (chewed cracker). The variable of interest was the proportion of successful trials, ranging from 0% to 100%. Higher values represent greater task performance.

2.4.2 | Crayon delay (age 2)

The Crayon Delay required children to inhibit themselves from coloring when left alone at a table with coloring supplies (Calkins, 1997). In this task, a research assistant placed a newly opened box of crayons and a blank sheet of paper in front of the child as the research assistant asked them if they would like to draw a picture. The child was then informed that the research assistant needed to briefly leave the room and the child was instructed not to touch the crayons, the box, or the paper until the research assistant returned (60-seconds later). The variable of interest was the latency (in seconds) to touch any of the coloring materials. Possible scores ranged from 0 to 60, and higher values represent greater task performance.

2.4.3 | Dimensional change card sort (DCCS; ages 2, 3, 4, and 6)

The Dimensional change card sort (DCCS) required children to manually sort a set of fourteen laminated cards based on one of two dimensions (either color or shape; Zelazo et al., 1996). Children were asked to sort the first seven cards by one dimension (the pre-switch condition; dimension was counterbalanced across participants), after which children were stopped and instructed to sort the remaining seven cards by the other dimension (the post-switch condition). At age 6, children who passed the post-switch condition were then administered the DCCS with borders. In this version of the task, children were required to sort the cards by one dimension for cards with borders (e.g., color) and by the other dimension for cards without borders (e.g., shape; also counterbalanced across participants). The variable of interest was the proportion of correct (a) pre-switch responses at age 2, (b) post-switch responses at ages 3 and 4, and (c) borders responses at age 6, ranging from 0% to 100%. Higher values represent greater task performance.

2.4.4 | Day/night (age 3)

Day/Night requires children to suppress the automatic response to label images depicted on a set of cards in favor of producing a contradictory verbal response (Gerstadt et al., 1994). In this task, children were instructed to say "day" when shown a card with a picture of a moon and to say "night" when shown a card with a picture of a sun. After two practice trials, children completed 16 test trials (8 sun cards and 8 moon cards) that were presented in a pseudorandom order. On each individual test trial, children received 1 point for a correct response, 0 points for an incorrect response, and 0.5 points for an incorrect response that the child self-corrected before moving to the next trial. Once the Day/Night task was completed, the number of points children earned across all 16 trials was summed to create a total point value. The variable of interest was the proportion of points earned, which was calculated by dividing the total point value by 16 (i.e., the number of trials completed), ranging from 0% to 100%. Higher values represent greater task performance.

2.4.5 | Digit span (ages 3, 4, and 6)

The forward digit span (FDS) task required 3 and 4 year old children to verbally repeat sequences of numbers in the order they were presented by a research assistant (Blankenship et al., 2019). Children were given two 2-digit practice trials, which were followed by the test trials that started at 2-digits and increased by one digit upon each successful response. The task was terminated after two consecutive failures of the same span. When children were 6 years of age, the backward digit span (BDS) task was used instead of the FDS. The administration of the BDS was nearly identical to the FDS, except children were instructed to repeat the number sequences backwards rather than forwards. The variable of interest for both the forward and backward DS task was digit span, which accounts for nonconsecutive errors.

2.4.6 | Gift peek (age 4)

Gift Peek requires children to inhibit the natural urge to peek as a researcher wraps an attractive gift for the child (i.e., a coloring pad and a box of 64 crayons; Kochanska et al., 2000). During this task, the child was told that the research assistant needed to wrap a gift for them. The child was instructed to stand and face a blank wall with their back to the research assistant, and the child was asked to not peek while the gift was wrapped (for 60-seconds) a few feet behind them in the same room. The variable of interest was the latency (in seconds) to peek as the child's gift was being wrapped. Possible scores ranged from 0 to 60, and higher values represent greater task performance.

2.4.7 | Number stroop (age 6)

This task is a computerized, number-based Stroop task (Ruffman et al., 2001). Children were shown rows of digits on a screen and they were required to count the number of digits (e.g., "777" = 3). Practice trials were provided prior to testing. Children recorded their responses on a keyboard and completed 25 test trials in total. The variable of interest was children's mean reaction time (RT; in seconds) for correct trials. For scale consistency across the age 6 tasks, children's RT scores were reverse coded such that larger values reflect faster RT and therefore greater task performance.

2.5 | Covariates

Child sex (1 = girl; 0 = boy) and maternal education (1 = college education; 0 = no college education) was recorded, as these variables have well-documented connections to child language and cognition in the literature (Bornstein & Cote, 2005; Hoff, 2003).

2.6 | Analytic plan

Descriptive statistics were generated for the primary variables of interest using IBM SPSS software (Version 22; see Table 2). Data were examined to determine multivariate normality, multicollinearity, and outliers. No evidence of non-normality was detected in the dataset (i.e., skewness ≤ 3 and kurtosis ≤ 10; Kline, 2011). Any values ($n = 10$) that were $\pm$ 3SD of the mean were classified as an outlier and were handled through Winsorization (i.e., these values were replaced by the next closest score; Salkind, 2010). The variables and total number of values that were Winsorized are as follows: PPVT at age 4 (> +3SD = 1); FDS at age 4 (> +3SD = 1); Day/Night at age 4 (< −3SD = 3); Number Stroop (prior to reverse scoring) at age 6 (> +3SD = 5). This procedure was done to retain variance in the data and to mitigate the bias that is associated with data trimming (Kwak & Kim, 2017).

A composite EF score was generated for each child at ages 2, 3, 4, and 6, as composites are more reliable than single EF assessments (Carlson et al., 2004). Composite values were created by standardizing and averaging the three EF variables at each age. The number of children who completed all three EF tasks at each timepoint are as follows: Age 2 ($n = 244$), age 3 ($n = 118$), age 4 ($n = 224$), and age 6 ($n = 179$). It should be noted that the FDS task was not administered for the 106 3-year-olds in cohort 1 as this task was not a part of the study protocol at the time of their age 3 lab visit (i.e., it was later added to the study). If a child was missing data for one of the three tasks at any given timepoint, their scores on the other two tasks were averaged and standardized in order to maximize statistical power. The number of children who only completed two out of the three EF tasks at each timepoint are as follows: Age 2 ($n = 70$; 45 children were missing Tongue Task data, 23 children were missing DCCS data, and 2 children were missing Crayon Delay data), age 3 ($n = 116$; 98 children were missing FDS data, 9 children were missing DCCS data, and 9 children were missing Day/Night data), age 4 ($n = 43$; 36 children were missing FDS data, 4 children were missing DCCS data, and 3 children were missing Gift Peek data), and age 6 ($n = 14$; 8 children were missing DCCS data, 4 children were missing BDS data, and 2 children were missing Number Stroop data). In the event that a child only completed one of the three EF tasks, however, their score was coded as missing for that timepoint because a composite value could not be computed. At each timepoint, the number of children who only completed one EF task were as follows: Age 2 ($n = 7$), age 3 ($n = 47$), age 4 ($n = 0$), and age 6 ($n = 1$). In total, 127 children had complete EF data as they had completed *at least* two EF tasks across all four data collection timepoints.

Analyses were conducted using SEM in Mplus (Version 8; Muthén & Muthén, 2012) with full information maximum likelihood (FIML) to account for missing data. This estimation approach utilizes all available data and results in less biased estimates/standard errors in comparison to other missing data techniques, such as listwise deletion (Enders, 2001). Power guidelines by MacCallum et al. (1996) indicated that a minimum sample of 200 children was needed to provide acceptable power to detect model fit (power ≥ 0.80; $\alpha = 0.05$). Inferential and descriptive indices of model fit were calculated: Chi-square (χ^2) test, root mean square error of approximation (RMSEA < 0.08;

TABLE 2 Descriptive statistics for primary study variables.

		N	Min	Max	Mean	Std. Dev.	Skew	Kurtosis
Vocabulary Measures								
Age 2	MCDI-W&S	333	5.00	680.00	303.23	172.88	0.18	−0.85
Age 3	PPVT	281	9.00	102.00	53.88	17.37	0.02	−0.13
Age 4	PPVT	264	27.00	137.00	76.58	19.70	0.04	0.07
Age 6	PPVT	194	77.00	167.00	123.16	16.76	0.18	0.08
Executive Functioning Measures								
Age 2	DCCS	292	0.00	1.00	0.63	0.24	0.05	−0.58
	Tongue Task	271	0.00	1.00	0.43	0.41	0.30	−1.51
	Crayon Delay	316	0.00	60.00	19.03	24.57	0.87	−1.01
Age 3	DCCS	262	0.00	1.00	0.45	0.44	0.19	−1.80
	FDS	138	1.00	4.00	2.86	0.87	−0.41	−0.86
	Day/Night	233	0.00	1.00	0.42	0.30	0.23	−1.09
Age 4	DCCS	263	0.00	1.00	0.62	0.45	−0.51	−1.60
	FDS	231	1.50	6.00	3.65	0.73	−0.35	0.91
	Gift Peek	264	0.00	60.00	43.31	22.67	−0.84	−1.04
Age 6	DCCS	185	0.08	1.00	0.66	0.20	−0.01	−0.46
	BDS	190	0.00	4.50	2.95	0.83	−0.52	0.21
	Stroop	191	1.70	7.49	3.71	1.16	1.09	1.23

Note: Descriptive statistics were generated after Winsorization.
Abbreviations: BDS, backward digit span; DCCS, dimensional change card sort task; FDS, forward digit span; MCDI-W&S, MacArthur-Bates communicative development inventory: Words and Sentences; PPVT, peabody picture vocabulary test; Stroop, number stroop (reaction time in seconds prior to reverse scoring).

MacCallum et al., 1996), and confirmatory fit index (CFI > 0.90; Hu & Bentler, 1999). The longitudinal associations between EF and vocabulary were analyzed using an autoregressive cross-lagged panel design with four waves of data. This statistical approach was selected as it allows for the examination of a) the longitudinal stability of vocabulary/EF (i.e., autoregressive paths) as well as b) unidirectional and/or bidirectional paths between vocabulary and EF (i.e., concurrent correlations and longitudinal cross-lagged paths). Chi-square difference tests ($\Delta\chi^2$) were used to compare the fit of one nested model to an alternate model.

3 | RESULTS

3.1 | Bivariate correlations

Correlations were examined between the primary study variables (Table 3). Children's vocabulary scores were positively intercorrelated at each data collection wave (ages 2, 3, 4, and 6) with the correlation coefficients (r) ranging from 0.31 to 0.77 (all $ps < 0.01$). Children's EF composite scores were also positively intercorrelated across data collection waves (ranging from 0.22 to 0.37; all $ps < 0.01$), with the exception of age 3 and age 6 EF which was not correlated, $r = 0.07$, $p = 0.43$. Point biserial correlations were then examined between the primary study variables and the covariates. Child sex was significantly correlated with children's vocabulary scores at age 2, $r = 0.17$, $p < 0.01$, and age 3, $r = 0.12$, $p = 0.05$. These positive associations indicate that when children were 2 and 3 years of age, girls exhibited larger vocabularies in comparison to boys. Child sex was only related to children's composite EF scores at age 3, $r = 0.15$, $p = 0.03$, where girls scored higher than boys in this sample on the age 3 EF tasks. Across all ages (2, 3, 4, and 6), maternal education was significantly correlated with children's vocabulary scores ($r = 0.15, 0.33, 0.29, 0.27$ respectively, all $ps < 0.01$) as well as with children's composite EF scores ($r = 0.16, 0.22, 0.29, 0.19$ respectively, all $ps < 0.01$). Given these significant associations, child sex and maternal education were controlled for in the longitudinal analyses described below.

3.2 | Autoregressive cross-lagged panel modeling

3.2.1 | Panel model without covariates (Model A)

Panel modeling was conducted with and without the covariates entered using children's EF composite values and vocabulary scores at ages 2, 3, 4, and 6. The fit indices demonstrated that the model without the covariates (Model A; Figure 1) fit the data adequately, $\chi^2(12) = 34.294$, $p < 0.001$; RMSEA = 0.07 (90% CI = 0.05–0.10); CFI = 0.96.

TABLE 3 Pearson correlation matrix for primary study variables.

	Age 2 Tasks					Age 3 Tasks					Age 4 Tasks					Age 6 Tasks				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Age 2 Tasks																				
1. MCDI-W&S	–																			
2. DCCS	0.10	–																		
3. TT	0.26**	0.17**	–																	
4. Crayon	0.18**	0.19**	0.20**	–																
5. EF_2	0.26**	0.68**	0.68**	0.71**	–															
Age 3 Tasks																				
6. PPVT	0.32**	0.13*	0.08	0.18**	0.20**	–														
7. DCCS	0.27**	0.09	0.06	0.23**	0.21**	0.26**	–													
8. FDS	0.26**	0.08	0.07	0.13	0.15	0.38**	0.16	–												
9. Day/Night	0.15*	0.11	0.19**	0.18**	0.22**	0.06	0.22**	0.03	–											
10. EF_3	0.33**	0.16*	0.16*	0.26**	0.29**	0.30**	0.74**	0.64**	0.72**	–										
Age 4 Tasks																				
11. PPVT	0.31**	0.07	0.01	0.08	0.09	0.77**	0.17*	0.28**	0.12	0.25**	–									
12. DCCS	0.38**	0.20**	0.16*	0.18**	0.28**	0.36**	0.22**	0.30**	0.05	0.23**	0.26**	–								
13. FDS	0.26**	0.02	0.06	0.10	0.10	0.24**	0.09	0.35**	0.19*	0.30**	0.24**	0.22**	–							
14. Gift Peek	0.16*	0.03	0.15*	0.11	0.15*	0.15*	0.03	0.17	0.23**	0.21**	0.09	0.24**	0.20**	–						
15. EF_4	0.38**	0.13*	0.16*	0.19**	0.25**	0.35**	0.16*	0.40**	0.23**	0.37**	0.27**	0.72**	0.70**	0.71**	–					
Age 6 Tasks																				
16. PPVT	0.41**	0.19*	0.14	0.27**	0.29**	0.61**	0.17*	0.29**	0.19*	0.28**	0.66**	0.38**	0.17*	0.25**	0.39**	–				
17. DCCS	0.14	0.22**	0.21*	0.12	0.27**	0.28**	0.11	0.27**	−0.02	0.19*	0.26**	0.21**	0.19*	0.05	0.21**	0.34**	–			
18. BDS	0.15*	0.15	−0.07	0.13	0.10	0.29**	−0.04	0.22*	0.00	0.09	0.21**	0.21**	0.24**	0.09	0.24**	0.33**	0.19**	–		
19. Stroop	0.04	0.25**	−0.02	−0.05	0.08	0.01	−0.19*	−0.04	−0.01	−0.13	−0.02	0.16*	0.17*	−0.05	0.12	0.16*	0.17*	0.21**	–	
20. EF_6	0.17*	0.31**	0.07	0.09	0.22**	0.27**	−0.06	0.18	0.01	0.07	0.21**	0.28**	0.28**	0.04	0.27**	0.39**	0.67*	0.70**	0.69**	–

Abbreviations: BDS, Backward Digit Span; Crayon, Crayon Delay; DCCS, Dimensional Change Card Sort task; EF_(#), EF composite score at a given measurement wave; FDS, Forward Digit Span; MCDI-W&S, MacArthur-Bates Communicative Development Inventory: Words and Sentences; PPVT, Peabody Picture Vocabulary Test; Stroop, Reverse scored Number Stroop (reaction time); TT, Tongue Task.

*$p < 0.05$; **$p < 0.01$.

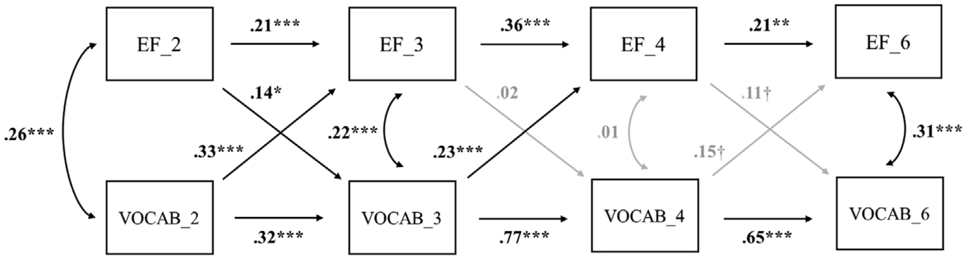

FIGURE 1 Model A: Autoregressive, cross-lagged panel model depicting the longitudinal associations between EF and vocabulary when children were 2, 3, 4, and 6 years of age. *Note*: †$p < 0.10$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. EF = executive functioning; VOCAB = vocabulary. Standardized estimates are presented. Solid black lines represent statistically significant paths; Solid gray lines represent non-significant paths.

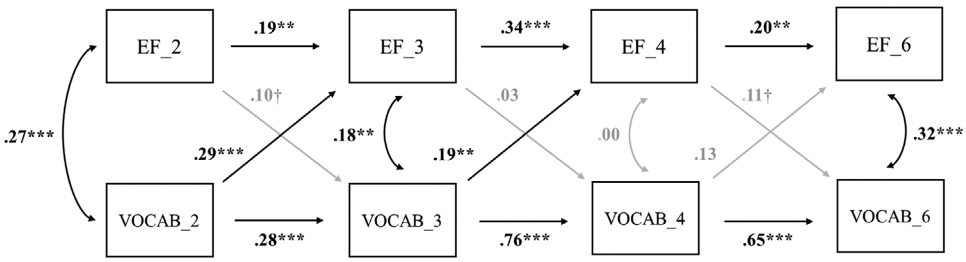

FIGURE 2 Model B: Autoregressive, cross-lagged panel model depicting the longitudinal associations between EF and vocabulary when children were 2, 3, 4, and 6 years of age after controlling for child sex and maternal education. *Note*: †$p < 0.10$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. Standardized estimates are presented. Solid black lines represent statistically significant paths; Solid gray lines represent non-significant paths.

Autoregressive pathways. As anticipated, the standardized coefficients for the autoregressive pathways of EF (ranging from 0.21 to 0.36) and vocabulary (ranging from 0.32 to 0.77) were all significant (all *ps* < 0.01). This finding represents a degree of stability in young children's EF and vocabulary scores over time, given that children's early scores were predictive of their scores at the next data collection wave.

Cross-lagged pathways. Children's age 2 vocabulary scores predicted their age 3 EF outcomes ($b = 0.33$, $SE = 0.06$, $p < 0.001$), and children's age 3 vocabulary scores predicted their age 4 EF outcomes ($b = 0.23$, $SE = 0.06$, $p < 0.001$). However, age 4 vocabulary did not predict age 6 EF ($b = 0.15$, $SE = 0.08$, $p = 0.061$). In contrast, only children's EF performance at age 2 was predictive of their age 3 vocabulary ($b = 0.14$, $SE = 0.06$, $p = 0.017$).

Residual correlations. Concurrent correlations between EF and vocabulary were significant at age 2 ($b = 0.26$, $SE = 0.05$, $p < 0.001$), age 3 ($b = 0.22$, $SE = 0.06$, $p < 0.001$), and age 6 ($b = 0.31$, $SE = 0.07$, $p < 0.001$).

3.2.2 | Panel model with covariates (Model B)

Next, a model with child sex and maternal education included (Model B; Figure 2) was examined and the fit indices were suggestive of mediocre model fit, $\chi^2(16) = 57.969$, $p < 0.001$; RMSEA = 0.09 (90% CI = 0.06–0.11); CFI = 0.92. Child sex did not significantly predict children's EF or vocabulary outcomes at any age. However, maternal education was associated with children's age 3 EF, age 3 vocabulary, and age 4 EF values (standardized coefficients ranged from 0.14 to 0.28; all $p < 0.05$). That is, children of mothers with a college degree scored higher on the PPVT at age 3 and on the battery of EF tasks at ages 3 and 4 in comparison to children of mothers without a college degree. After controlling for child sex and maternal education, the cross-lagged path between age 2 EF and age 3 vocabulary ($b = 0.10$, $SE = 0.06$, $p = 0.084$) was no longer significant. The chi-square difference test was used to formally evaluate which nested model better fit the data (i.e., Model A or Model B). The test indicated that Model A fit the data significantly better than Model B ($\Delta\chi^2 = 23.675$, $\Delta df = 4$, $p = 0.05$).

3.2.3 | Trimmed panel model (Model C)

Despite Model B's poorer fit, Models A and B demonstrated the following: (1) after age 3, the cross-lagged paths between children's early EF and later vocabulary scores were not significant, (2) there were no significant paths between child sex and EF or vocabulary at any age, (3) maternal education was not related to children's later EF (at age 6) and vocabulary (at ages 4 and 6) outcomes, and (4) the covariation between age 4 vocabulary and age 4 EF was not significant. These nonsignificant variables and paths were therefore removed in a final, trimmed model (Model C; Figure 3), which demonstrated acceptable and comparatively improved model fit, $\chi^2(20) = 49.392$, $p < 0.001$; RMSEA = 0.06 (90% CI = 0.04–0.09); CFI = 0.95. In comparison to Models A and B, the

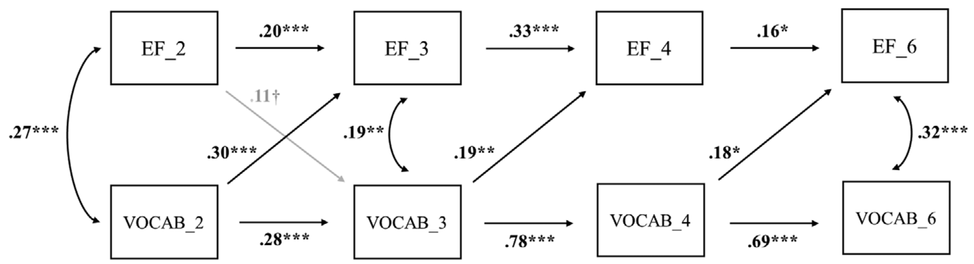

FIGURE 3 Model C: The best-fitting autoregressive, cross-lagged panel model depicting the longitudinal associations between EF and vocabulary when children were 2, 3, 4, and 6 years of age. *Note*: †$p < 0.10$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. Standardized estimates are presented. Solid black lines represent statistically significant paths; Solid gray lines represent nonsignificant paths.

direct path in Model C between children's age 4 vocabulary scores and their age 6 EF outcomes was significant ($b = 0.18$, $SE = 0.08$, $p = 0.024$). The Chi-square difference test was used to compare model fit between Model A and Model C. The test indicated that the trimmed model, Model C, better fit the data ($\Delta\chi^2 = 15.098$, $\Delta df = 8$, $p = 0.05$). These findings suggest that after controlling for maternal education, the best-fitting longitudinal model in this study was a unidirectional cross-lagged model for which vocabulary size at ages 2, 3, and 4 predicted children's later EF performance at ages 3, 4, and 6.

4 | DISCUSSION

Although a wealth of research illustrates that child vocabulary and EF are positively correlated (Carlson et al., 2004; Fuhs & Day, 2011; Kuhn et al., 2014; Wolfe & Bell, 2004), relatively few studies have investigated this relation over time across the span of early childhood. Among the studies that have adopted a longitudinal framework, however, inconsistent findings have been documented in both the direction and magnitude of the predictive link between EF and vocabulary (Gooch et al., 2016; McClelland et al., 2014; Whedon et al., 2018). Some of the discrepancies reported in the developmental literature may be due in part to the diverse methodologies adopted by early childhood researchers, who have often relied on two-wave measurement studies conducted with preschool samples. The current study therefore sought to advance this area of research by examining the longitudinal associations between EF and vocabulary in order to address the directionality of these relations starting in toddlerhood (age 2) and extending up to the elementary school years (age 6). It was hypothesized that a bidirectional pattern of associations would be detected across all four data collection waves. That is, we anticipated that early vocabulary size would predict children's later EF performance (Hypothesis 1), and that early EF abilities would predict children's later vocabulary size (Hypothesis 2). Not surprisingly, children's EF composite values were positively correlated with their vocabulary scores both within and across measurement waves. Between the three panel models generated, however, an interesting pattern of cross-lagged paths emerged.

First, Hypothesis 1 was fully supported as children's expressive/receptive vocabulary size at ages 2, 3, and 4 significantly predicted their respective EF performance at ages 3, 4, and 6. This finding illustrates that across early childhood, the size of children's vocabulary at one timepoint was predictive of their EF performance at the next timepoint, even after controlling for children's initial EF scores, child sex, and maternal education. Among the available longitudinal research, similar findings have been reported at various developmental timepoints in early childhood (Fuhs et al., 2014; Hughes & Ensor, 2007; Kuhn et al., 2014; Wade et al., 2014; Whedon et al., 2018). For instance, Hughes and Ensor (2007) illustrate that children's combined expressive/receptive vocabulary size at ages 2 and 3 was predictive of their EF outcomes at ages 3 and 4. Among a sample of slightly older children, Wade et al. (2014) also report that children's PPVT scores at age 3 predicted their EF skills when measured at 4.5 years. The current study extends these findings by replicating this unidirectional pathway between vocabulary and EF across a wider age range in early childhood and having controlled for relevant covariates as well as children's initial EF scores.

In contrast, Hypothesis 2 was partially supported as the only significant cross-lagged path between early EF and later vocabulary was found between children's EF scores at age 2 and their vocabulary size at age 3. This pathway was no longer significant, however, once maternal education was introduced in the model. These findings collectively suggest that it is only children's early EF abilities in toddlerhood that are predictive of their vocabulary size one year later, although EF performance at age 2 did not account for unique variance in age 3 vocabulary above and beyond maternal education. Situating these findings in the developmental literature is difficult because of the dearth of research examining the longitudinal link between early EF and later vocabulary, especially prior to the preschool/kindergarten years. Among the research that is available, however, mixed findings have been reported. For example, while McClelland et al. (2014) demonstrate that children's EF scores at the start of preschool predicted their vocabulary size at the end of the preschool year, Petersen et al. (2014) report that children's EF scores in toddlerhood did not predict their vocabulary outcomes later in toddlerhood or during the preschool years. In closely examining the battery of EF tasks that were administered in these two studies, considerable differences are apparent in the amount of language these task batteries required. Unlike Petersen et al. (2014), McClelland et al. (2014) utilized multiple EF tasks that place heavy verbal demands on children, such as the Head-Toes-Knees-Shoulders (HTKS) task or the Woodcock Johnson (III) Auditory Working Memory test. If the predictive link between early EF and later vocabulary is indeed driven in part by an overlap in verbal ability as some researchers suggest (Kaushanskaya et al., 2017), then the cross-lagged effects in this direction may not have been significant in our study because multiple linguistically simple EF tasks were administered. Furthermore, early vocabulary may differentially relate to children's EF skills as a function of tasks' emotional content. Garon et al. (2008) discuss that while some EF tasks can be classified as emotionally neutral (e.g., digit span or conflict tasks), others are more motivational in nature (e.g., delay-of-gratification tasks) and may therefore also require emotion regulation skills. Although all of the EF tasks administered in the current study are developmentally appropriate and empirically established, the EF tasks administered at age 3 and age 6 are all arguably emotionally neutral. Taken together, additional research is warranted to better understand the role of EF task selection in terms of the association between EF and vocabulary in early childhood.

Although not of primary interest, the autoregressive effects in the panel models indicate that there is stability in children's vocabulary size and EF performance over time across early childhood. This means that on average, as an example, children who scored high on the PPVT at age 3 also scored high on the PPVT when measured at the age 4 lab visit. The autoregressive paths for EF and vocabulary displayed moderate and very strong continuity, respectively. This finding is not surprising given that (a) vocabulary was measured in the current study as opposed to language more broadly and (b) vocabulary was assessed using the PPVT repeatedly across measurement waves. Having evaluated child EF and language using the exact same measures at ages 4, 5, and 6, Gooch et al. (2016) also report considerable stability in both children's EF and language skills over time. These authors demonstrate that none of cross-lagged paths were statistically significant in their study, which they relate to the strong autoregressive effects that were found. Indeed, larger autoregressive coefficients are reflective of little variance over time (Kearney, 2016). It's therefore also possible that the cross-lagged effects from EF to vocabulary were not significant in our study because children exhibited such strong stability in their vocabulary scores across early childhood. Taken together, these results illustrate that after controlling for maternal education as a proxy for socioeconomic factors (Pace et al., 2017), the best-fitting longitudinal model was a unidirectional model wherein children's early vocabulary size predicted their later EF outcomes. This finding suggests that at multiple points across the early childhood period, having a large vocabulary at one's disposal aids children in their performance on a battery of challenging and effortful cognitive tasks.

What remains unclear from the findings presented above is the mechanism(s) underlying the longitudinal association between vocabulary and EF observed across early childhood. In discussing the link between EF deficits and language impairment reported in the literature, Bishop et al. (2014) argue that this association may operate at either the superficial or the deep level. In other words, early vocabulary size may predict later EF performance because EF tasks require children to comprehend verbal instructions (the superficial level) or because word knowledge is essential to plan, monitor, and adjust one's behavior during challenging situations (the deep level). Measurement problems aside, one potential explanation based on developmental theory is that early vocabulary may be essential to the successful execution of goal-oriented activities early in life via self-directed or private speech. In contrast to Piaget and Inhelder's (1969) view of private speech as a reflection of children's cognitive immaturity, Vygotsky (1962, 1978) regarded private speech as being critical to the development of self-control via higher order cognitive operations in childhood. That is to say, children rely on culturally-bound symbols (e.g., words) in the service of manipulating and self-guiding thought/action, which become internalized over the course of development (Vallotton & Ayoub, 2011). Both the content and amount of private speech used by children is associated with their performance on tasks that require planning, directing, and problem-solving skills during the preschool years (Azmitia, 1992; Behrend et al., 1989; Mulvihill et al., 2021). For example, Mulvihill et al. (2021) demonstrate that preschoolers who produced more task-relevant private speech (i.e., speech that involved self-instructional or self-motivational statements) experienced greater success on a card sorting task and a Duplo construction task. Even among studies with older children, age-related differences have been observed in the content of children's self-verbalizations when "thinking out loud" on a cued switching task. Although 5-year-olds frequently verbalized the target (i.e., they named the object they saw), Karbach and Kray (2007) report that 9-year-olds consistently verbalized the instructional cue + response (i.e., they named the sorting rule and required action). Thus, further mechanistic work is necessary to uncover whether early word knowledge and/or production skills enable children to engage in self-directed speech, which appears to play an important role in the organization and direction of effortful, goal-oriented action.

4.1 | Limitations and future directions

The current study illustrates an informative developmental pattern of associations between EF and vocabulary as measured at various points across the early childhood period. These findings should be considered in light of the current study's limitations. First, because the PPVT (receptive vocabulary; a behavioral assessment) is normed for children starting at 30-months and the MCDI (expressive vocabulary; a parent-report measure) is normed for children between the ages of 16- to 30-months, we were unable to measure both receptive and expressive vocabulary at each timepoint or only receptive or expressive vocabulary using the same instrument at each data collection wave. Of course, children's expressive vocabulary size at age 2 was significantly correlated with their receptive vocabulary scores at ages 3, 4, and 6, and the autoregressive path between age 2 and age 3 vocabulary was strong. However, future research should consider incorporating measures of child verbal skill that are normed for a wider developmental age range, such as the Mullen Scales of Early Learning. Likewise, because it is important to administer developmentally-appropriate EF tasks at each age, the exact same EF tasks were not administered at each measurement wave. Despite EF task differences, however, the task selection criteria were consistent across all timepoints and the autoregressive paths illustrate considerable stability in EF performance from age 2 through age 6.

Next, aspects of children's language development that extend beyond expressive or receptive vocabulary (e.g., grammar or pragmatics) were not assessed in the present study. Moreover, the measures used to assess vocabulary in the current study may not have captured the full breadth of children's word knowledge and/or production abilities. Although considerably less research has examined the association between EF and children's language skills more broadly, there is some evidence to suggest that EF may be related to an array of linguistic processes (Blain-Brière et al., 2014; Marini et al., 2020; White et al., 2017; Woodard et al., 2016). Further research examining the bidirectional links between EF and language is warranted, especially since improvements in some linguistic skills (e.g., children's understanding and use of decontextualized speech; Uccelli et al., 2019) typically emerge later in early childhood.

Although the current study extended the literature by examining the relation between EF and vocabulary well before the preschool years, the findings presented above cannot speak to the association or lack thereof in infancy when children's rudimentary cognitive-linguistic skills are starting to emerge. Very few studies have examined the relation between these processes in infancy, although there is some evidence to suggest they may be related earlier in the second postnatal year. For example, Miller and Marcovitch (2015) report that infants' receptive vocabulary size at 14-months was predictive of the number of EF tasks passed at 18-months. Thus, additional work is necessary beginning even earlier in childhood to elucidate the role rudimentary EF and vocabulary skills may play in predicting children's later cognitive-linguistic outcomes.

Finally, although effort was exerted between the two research locations to recruit a more representative sample of children, the majority of children in this sample are White and have mothers who have obtained at least a 4-year college degree. Indeed, maternal education is highly correlated with caregiver factors found to be related to child development, such as sensitive and stimulating parenting behaviors (Huang et al., 2022). In recruiting a sample of children whose mothers are predominately highly educated, the data may inadvertently reflect the associations between EF and vocabulary among a subsample of child with more responsive caregivers who speak frequently with their children. Likewise, the current study is also constrained by its focus on monolingual and typically-developing children. However, an examination of bilingual and/or neurodiverse child trajectories may provide additional insight into the relation between EF and vocabulary (or language more broadly), as well as mechanisms that may underlie this association. Taken together, replication research is essential in order to examine whether these findings generalize to more diverse samples of children, and effort should be taken to ascertain whether contextual factors (e.g., parenting) or child-centric factors (e.g., temperament) influence the longitudinal relations between EF and vocabulary in early childhood. Despite these limitations, the longitudinal nature of the present study is a clear strength, in addition to the robust methodological/analytic approach that was implemented and the large sample size collected across an extensive developmental age range.

4.2 | Conclusion

Because early EF and vocabulary development are critical to a host of academic and self-regulatory outcomes (Blair & Razza, 2007; Longobardi et al., 2016; Moll et al., 2015), understanding the developmental progression of these interrelated processes is essential to establishing early childhood interventions. Despite evidence to support the concurrent association between EF and vocabulary in childhood, inconsistent findings have been reported regarding the extent to which early EF and vocabulary abilities predict children's later outcomes respectively. Thus, the objective of our study was to investigate the longitudinal link between EF and vocabulary across four measurement waves in early childhood. After controlling for maternal education, the best-fitting cross-lagged panel model was a unidirectional model, whereby children's early vocabulary scores were predictive of their later EF performance at each timepoint. Coupled with previous longitudinal research on this topic, our findings indicate that early vocabulary abilities play an important role in predicting children's later self-modulated and goal-directed actions at various timepoints across early childhood.

ACKNOWLEDGMENTS

We thank the families in Blacksburg, VA and Greensboro, NC for their continued participation in our study, as well as Susan D. Calkins and her team at the University of North Carolina at Greensboro for their dedication to this project. The content of this manuscript is solely the responsibility of the authors and does not necessarily represent the official views of the NICHD or the National Institutes of Health. This work was funded by the Eunice Kennedy Shriver National Institute of Child Health and Human Development, Grant/Award Number: R01 HD049878 awarded to M.A.B (Principal Investigator).

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Madeleine Bruce https://orcid.org/0000-0001-5056-2587
Jyoti Savla https://orcid.org/0000-0001-7142-3770
Martha Ann Bell https://orcid.org/0000-0001-9222-0374

REFERENCES

Alcock, K. J. (2017). Production is only half the story—First words in two East African languages. *Frontiers in Psychology*, *8*, Article1898. https://doi.org/10.3389/fpsyg.2017.01898

Alduncin, N., Huffman, L. C., Feldman, H. M., & Loe, I. M. (2014). Executive function is associated with social competence in preschool-aged children born preterm or full term. *Early Human Development*, *90*(6), 299–306. https://doi.org/10.1016/j.earlhumdev.2014.02.011

Anglin, J. M. (1993). Vocabulary development: A morphological analysis. *Monographs of the Society for Research in Child Development*, *58*(10), 176–186. https://doi.org/10.2307/1166112

Azmitia, M. (1992). Expertise, private speech, and the development of self-regulation. In (R. M. Diaz & L. E. Berk Eds.), *Private speech: From social interaction to self-regulation* (pp. 101–122). Lawrence Erlbaum Associates, Inc.

Bates, E., Marchman, V., Thal, D., Fenson, L., Dale, P., Reznick, J. S., Reilly, J., & Hartung, J. (1994). Developmental and stylistic variation in the composition of early vocabulary. *Journal of Child Language*, *21*(1), 85–123. https://doi.org/10.1017/s0305000900008680

Beck, D. M., Schaefer, C., Pang, K., & Carlson, S. M. (2011). Executive function in preschool children: Test-retest reliability. *Journal of Cognition and Development*, *12*(2), 169–193. https://doi.org/10.1080/15248372.2011.563485

Behrend, D. A., Rosengren, K., & Perlmutter, M. (1989). A new look at children's private speech: The effects of age, task difficulty, and parent presence. *International Journal of Behavioral Development*, *12*(3), 305–320. https://doi.org/10.1177/016502548901200302

Bell, M. A. (2012). A psychobiological perspective on working memory performance at 8 months of age. *Child Development*, *83*(1), 251–265. https://doi.org/10.1111/j.1467-8624.2011.01684.x

Bell, M. A., & Garcia-Meza, T. (2020). Executive function. In (J. B. Benson Eds.), *Encyclopedia of infant and early childhood development*, (2nd edn.). (Vol, 1, pp. 568–574). Elsevier. https://doi.org/10.1017/CBO9780511606441.017

Bell, M. A., Phillips, J. J., & Bruce, M. D. (2022). Infant and toddler working memory. In (M. L. Courage & N. Cowan Eds.), *The development of memory in infancy and childhood*, (3rd edn.). (pp. 87–110). Routledge Press. https://doi.org/10.4324/9781003016533-4

Bishop, D. V. M., Nation, K., & Patterson, K. (2014). When words fail us: Insights into language processing from developmental and acquired disorders. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1634), 20120403. https://doi.org/10.1098/rstb.2012.0403

Blain-Brière, B., Bouchard, C., & Bigras, N. (2014). The role of executive functions in the pragmatic skills of children age 4–5. *Frontiers in Psychology*, *5*, Article240. https://doi.org/10.3389/fpsyg.2014.00240

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development*, *78*(2), 647–663. https://doi.org/10.1111/j.1467-8624.2007.01019.x

Blakey, E., Visser, I., & Carroll, D. J. (2016). Different executive functions support different kinds of cognitive flexibility: Evidence from 2-, 3-, and 4-year-olds. *Child Development*, *87*(2), 513–526. https://doi.org/10.1111/cdev.12468

Blankenship, T. L., Slough, M. A., Calkins, S. D., Deater-Deckard, K., Kim-Spoon, J., & Bell, M. A. (2019). Attention and executive functioning in infancy: Links to childhood executive function and reading achievement. *Developmental Science*, *22*(6), e12824. https://doi.org/10.1111/desc.12824

Blankson, A. N., O'Brien, M., Leerkes, E. M., Marcovitch, S., & Calkins, S. D. (2011). Shyness and vocabulary: The roles of executive functioning and home environmental stimulation. *Merrill-Palmer Quarterly*, *57*(2), 105–128. https://doi.org/10.1353/mpq.2011.0007

Bloom, L., & Lahey, M. (1978). *Language development and language disorders.* John Wiley & Sons, Inc.

Bornstein, M. H., & Cote, L. R. (2005). Expressive vocabulary in language learners from two ecological Settings in three language communities. *Infancy*, *7*(3), 299–316. https://doi.org/10.1207/s15327078in0703_5

Bruce, M., & Bell, M. A. (2022). Vocabulary and executive functioning: A scoping review of the unidirectional and bidirectional associations across early childhood. *Human Development*, *66*, 167–187. https://doi.org/10.1159/000524964

Calkins, S. D. (1997). Cardiac vagal tone indices of temperamental reactivity and behavioral regulation in young children. *Developmental Psychobiology*, *31*(2), 125–135. https://doi.org/10.1002/(SICI)1098-2302(199709)31:2⟨125::AID-DEV5⟩3.0.CO;2-M

Carlson, S. M., Davis, A. C., & Leach, J. G. (2005). Less is more: Executive function and symbolic representation in preschool children. *Psychological Science*, *16*(8), 609–616. https://doi.org/10.1111/j.1467-9280.2005.01583.x

Carlson, S. M., Mandell, D. J., & Williams, L. (2004). Executive function and theory of mind: Stability and prediction from ages 2 to 3. *Developmental Psychology*, *40*(6), 1105–1122. https://doi.org/10.1037/0012-1649.40.6.1105

Childers, J. B., & Tomasello, M. (2002). Two-year-olds learn novel nouns, verbs, and conventional actions from massed or distributed exposures. *Developmental Psychology*, *38*(6), 967–978. https://doi.org/10.1037/0012-1649.38.6.967

Chung, K. K. H., & McBride-Chang, C. (2011). Executive functioning skills uniquely predict Chinese word reading. *Journal of Educational Psychology*, *103*(4), 909–921. https://doi.org/10.1037/a0024744

Community-University Partnership for the Study of Children, Youth, and Families (2011). Review of the Peabody Picture Vocabulary Test, Fourth Edition (PPVT-4).

Cuevas, K., & Bell, M. A. (2014). Infant attention and early childhood executive function. *Child Development*, *85*(2), 397–404. https://doi.org/10.1111/cdev.12126

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Diamond, A. (2002). Normal development of prefrontal cortex from birth to young adulthood: Cognitive functions, anatomy, and biochemistry. In (D. T. Stuss & R. T. Knight Eds.), *Principles of frontal lobe function* (pp. 466–503). Oxford Scholarship Online. https://doi.org/10.1093/acprof:oSo/9780195134971.003.0029

Diamond, A., Prevor, M. B., Callender, G., & Druin, D. P. (1997). Prefrontal cortex cognitive deficits in children treated early and continuously for PKU. *Monographs of the Society for Research in Child Development*, *62*(4), 1–208. https://doi.org/10.2307/1166208

Dunn, L. M., & Dunn, D. M. (2007). *The peabody picture vocabulary test, Fourth Edition.* NCS Pearson, Inc.

Enders, C. K. (2001). The performance of the full information maximum likelihood estimator in multiple regression models with missing data. *Educational and Psychological Measurement*, *61*(5), 713–740. https://doi.org/10.1177/00131640121971482

Espy, K. A., Kaufmann, P. M., McDiarmid, M. D., & Glisky, M. L. (1999). Executive functioning in preschool children: Performance on A-not-B and other delayed response format tasks. *Brain and Cognition*, *41*(2), 178–199. https://doi.org/10.1006/brcg.1999.1117

Espy, K. A., McDiarmid, M. M., Cwik, M. F., Stalets, M. M., Hamby, A., & Senn, T. E. (2004). The contribution of executive functions to emergent mathematic skills in preschool children. *Developmental Neuropsychology*, *26*(1), 465–486. https://doi.org/10.1207/s15326942dn2601_6

Fenson, L., Dale, P. S., Reznick, J. S., Bates, E., Thal, D. J., & Pethick, S. J. (1994). Variability in early communicative development. *Monographs of the Society for Research in Child Development*, *59*(5), 1–173. https://doi.org/10.2307/1166093

Fenson, L., Marchman, V. A., Thal, D. J., Dale, P. S., Reznick, J. S., & Bates, E. (2007). *MacArthur-bates communicative development inventories: User's guide and technical manual* (2nd edn.). Paul H. Brookes.

Fiske, A., & Holmboe, K. (2019). Neural substrates of early executive function development. *Developmental Review*, *52*, 42–62. https://doi.org/10.1016/j.dr.2019.100866

Fuhs, M. W., & Day, J. D. (2011). Verbal ability and executive functioning development in preschoolers at Head Start. *Developmental Psychology*, *47*(2), 404–416. https://doi.org/10.1037/a0021065

Fuhs, M. W., Nesbitt, K. T., Farran, D. C., & Dong, N. (2014). Longitudinal associations between executive functioning and academic skills across content areas. *Developmental Psychology*, *50*(6), 1698–1709. https://doi.org/10.1037/a0036633

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin*, *134*(1), 31–60. https://doi.org/10.1037/0033-2909.134.1.31

Gathercole, S. E., & Baddeley, A. D. (1989). Evaluation of the role of phonological STM in the development of vocabulary in children: A longitudinal study. *Journal of Memory and Language*, *28*(2), 200–213. https://doi.org/10.1016/0749-596X(89)90044-2

Gentner, D. (1982). Why nouns are learned before verbs: Linguistic relativity versus natural partitioning. In (S. A. Kuczaj Ed.), *Language development: Vol. 2. Language, thought and culture* (pp. 301–334). Lawrence Erlbaum Associates.

Gerstadt, C. L., Hong, Y. J., & Diamond, A. (1994). The relationship between cognition and action: Performance of children 3 1/2-7 years old on a Stroop-like day-night test. *Cognition*, *53*(2), 129–153. https://doi.org/10.1016/0010-0277(94)90068-x

Girard, L.-C., Pingault, J.-B., Falissard, B., Boivin, M., Dionne, G., & Tremblay, R. E. (2014). Physical aggression and language ability from 17 to 72 months: Cross-lagged effects in a population sample. *PLoS ONE*, *9*(11), e11218. https://doi.org/10.1371/journal.pone.0112185

Gooch, D., Thompson, P., Nash, H. M., Snowling, M. J., & Hulme, C. (2016). The development of executive function and language skills in the early school years. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *57*(2), 180–187. https://doi.org/10.1111/jcpp.12458

Hart, B., & Risley, T. R. (1995). *Meaningful differences in the everyday experience of young American children*. Paul H Brookes Publishing.

Harvey, H. A., & Miller, G. E. (2017). Executive function skills, early mathematics, and vocabulary in Head Start preschool children. *Early Education and Development*, *28*(3), 290–307. https://doi.org/10.1080/10409289.2016.1218728

Hoff, E. (2003). The specificity of environmental influence: Socioeconomic status affects early vocabulary development via maternal speech. *Child Development*, *74*(5), 1368–1378. https://doi.org/10.1111/1467-8624.00612

Howard, S. J., & Melhuish, E. (2017). An early years toolbox for assessing early executive function, language, self-regulation, and social development: Validity, reliability, and preliminary norms. *Journal of Psychoeducational Assessment*, *35*(3), 255–275. https://doi.org/10.1177/0734282916633009

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

Huang, W., Weinert, S., Wareham, H., Law, J., Attig, M., von Maurice, J., & Roßbach, H. G. (2022). The emergence of 5-year-olds' behavioral difficulties: Analyzing risk and protective pathways in the United Kingdom and Germany. *Frontiers in Psychology*, *12*, 769057. https://doi.org/10.3389/fpsyg.2021.769057

Hughes, C., & Ensor, R. (2007). Executive function and theory of mind: Predictive relations from ages 2 to 4. *Developmental Psychology*, *43*(6), 1447–1459. https://doi.org/10.1037/0012-1649.43.6.1447

Huttenlocher, J., Haight, W., Bryk, A., Seltzer, M., & Lyons, T. (1991). Early vocabulary growth: Relation to language input and gender. *Developmental Psychology*, *27*(2), 236–248. https://doi.org/10.1037/0012-1649.27.2.236

Joyce, A. W., Kraybill, J. H., Chen, N., Cuevas, K., Deater-Deckard, K., & Bell, M. A. (2016). A longitudinal investigation of conflict and delay inhibitory control in toddlers and preschoolers. *Early Education and Development*, *27*(6), 788–804. https://doi.org/10.1080/10409289.2016.1148481

Kapa, L. L., & Colombo, J. (2014). Executive function predicts artificial language learning. *Journal of Memory and Language*, *76*, 237–252. https://doi.org/10.1016/j.jml.2014.07.004

Karbach, J., & Kray, J. (2007). Developmental changes in switching between mental task sets: The influence of verbal labeling in childhood. *Journal of Cognition and Development*, *8*(2), 205–236. https://doi.org/10.1080/15248370701202430

Kaushanskaya, M., Park, J. S., Gangopadhyay, I., Davidson, M. M., & Weismer, S. E. (2017). The relationship between executive functions and language abilities in children: A latent variables approach. *Journal of Speech, Language, and Hearing Research*, *60*(4), 912–923. https://doi.org/10.1044/2016_JSLHR-L-15-0310

Kearney, M. W. (2016). Cross lagged panel analysis. In (M. R. Allen Eds.), *The SAGE encyclopedia of communication research methods* (pp. 312–314). Sage. https://doi.org/10.4135/9781483381411.n117

Kline, R. B. (2011). *Principles and practice of structural equation modeling* (3rd edn.). Guilford Press.

Kochanska, G., Murray, K. T., & Harlan, E. T. (2000). Effortful control in early childhood: Continuity and change, antecedents, and implications for social development. *Developmental Psychology*, *36*(2), 220–232. https://doi.org/10.1037/0012-1649.36.2.220

Kraybill, J. H., Kim-Spoon, J., & Bell, M. A. (2019). Infant attention and age 3 executive function. *The Yale Journal of Biology and Medicine*, *92*(1), 3–11. PMID: 30923468.

Kuhl, P. K. (2007). Is speech learning 'gated' by the social brain? *Developmental science*, *10*(1), 110–120. https://doi.org/10.1111/j.1467-7687.2007.00572.x

Kuhn, L. J., Willoughby, M. T., Vernon-Feagans, L., & Blair, C. B. (2016). The contribution of children's time-specific and longitudinal expressive language skills on developmental trajectories of executive function. *Journal of Experimental Child Psychology*, *148*, 20–34. https://doi.org/10.1016/j.jecp.2016.03.008

Kuhn, L. J., Willoughby, M. T., Wilbourn, M. P., Vernon-Feagans, L., & Blair, C. B. (2014). Early communicative gestures prospectively predict language development and executive function in early childhood. *Child Development*, *85*(5), 1898–1914. https://doi.org/10.1111/cdev.12249

Kwak, S. K., & Kim, J. H. (2017). Statistical data preparation: Management of missing values and outliers. *Korean Journal of Anesthesiology*, *70*(4), 407–411. https://doi.org/10.4097/kjae.2017.70.4.407

Longobardi, E., Spataro, P., Frigerio, A., & Rescorla, L. (2016). Language and social competence in typically developing children and late talkers between 18 and 35 months of age. *Early Child Development and Care*, *186*(3), 436–452. https://doi.org/10.1080/03004430.2015.1039529

MacCallum, R. C., Browne, M. W., & Sugawara, H. M. (1996). Power analysis and determination of sample size for covariance structure modeling. *Psychological Methods*, *1*(2), 130–149. https://doi.org/10.1037/1082-989X.1.2.130

Marini, A., Piccolo, B., Taverna, L., Berginc, M., & Ozbič, M. (2020). The complex relation between executive functions and language in preschoolers with developmental language disorders. *International Journal of Environmental Research and Public Health*, *17*(5), 1772. https://doi.org/10.3390/ijerph17051772

Matte-Gagné, C., & Bernier, A. (2011). Prospective relations between maternal autonomy support and child executive functioning: Investigating the mediating role of child language ability. *Journal of Experimental Child Psychology*, *110*(4), 611–625. https://doi.org/10.1016/j.jecp.2011.06.006

McClelland, M. M., Cameron, C. E., Duncan, R., Bowles, R. P., Acock, A. C., Miao, A., & Pratt, M. E. (2014). Predictors of early growth in academic achievement: The head-toes-knees-shoulders task. *Frontiers in Psychology*, *5*, 599. https://doi.org/10.3389/fpsyg.2014.00599

Miller, S. E., & Marcovitch, S. (2015). Examining executive function in the second year of life: Coherence, stability, and relations to joint attention and language. *Developmental Psychology*, *51*(1), 101–114. https://doi.org/10.1037/a0038359

Moll, K., Snowling, M. J., Göbel, S. M., & Hulme, C. (2015). Early language and executive skills predict variations in number and arithmetic skills in children at family-risk of dyslexia and typically developing controls. *Learning* *and Instruction*, *38*, 53–62. https://doi.org/10.1016/j.learninstruc.2015.03.004

Mulvihill, A., Matthews, N., Dux, P. E., & Carroll, A. (2021). Preschool children's private speech content and performance on executive functioning and problem-solving tasks. *Cognitive Development*, *60*, https://doi.org/10.1016/j.cogdev.2021.101116

Muthén, L. K., & Muthén, B. O. (2017). *Mplus User's Guide [Computer Software and Manual* (7th edn.).], Muthén & Muthén.

Netelenbos, N., Robbin, G. L., Fangfang, L., & Gonzalez, C. L. R. (2018). Articulation speaks to executive function: An investigation in 4- to 6-year-olds. *Frontiers in Psychology*, *9*, 172. https://doi.org/10.3389/fpsyg.2018.00172

Newman, R. S., Rowe, M. L., & Bernstein Ratner, N. (2016). Input and uptake at 7 months predicts toddler vocabulary: The role of child-directed speech and infant processing skills in language development. *Journal of Child Language*, *43*(5), 1158–1173. https://doi.org/10.1017/S0305000915000446

Oller, D. K. (1980). The emergence of the sounds of speech in infancy. In (G. H. Yeni-Komshian, J. F. Kavanagh, & C. A. Ferguson Eds.), *Child Phonology, Volume 1: Production* (pp. 93–112). Academic Press.

Pace, A., Luo, R., Hirsh-Pasek, K., & Golinkoff, R. M. (2017). Identifying pathways between socioeconomic status and language development. *Annual Review of Linguistics*, *3*, 285–308. https://doi.org/10.1146/annurev-linguistics-011516-034226

Petersen, I. T., Bates, J. E., & Staples, A. D. (2014). The role of language ability and self-regulation in the development of inattentive-hyperactive behavior problems. *Development and Psychopathology*, *27*(1), 221–237. https://doi.org/10.1017/S0954579414000698

Piaget, J., & Inhelder, B. (1969). *The psychology of the child*. (H. Weaver, Trans.). Basic Books.

Polka, L., & Werker, J. F. (1994). Developmental changes in perception of nonnative vowel contrasts. *Journal of Experimental Psychology: Human Perception and Performance*, *20*(2), 421–435. https://doi.org/10.1037/0096-1523.20.2.421

Ruffman, T., Rustin, C., Garnham, W., & Parkin, A. J. (2001). Source monitoring and false memories in children: Relation to certainty and executive functioning. *Journal of Experimental Child Psychology*, *80*(2), 95–111. https://doi.org/10.1006/jecp.2001.2632

Salkind, N. J. (2010). *Encyclopedia of research design*. SAGE Publications, Inc. https://doi.org/10.4135/9781412961288

Schmitt, S. A., Purpura, D. J., & Elicker, J. G. (2019). Predictive links among vocabulary, mathematical language, and executive functioning in preschoolers. *Journal of Experimental Child Psychology*, *180*, 55–68. https://doi.org/10.1016/j.jecp.2020.104921

Shipley, K. G., & McAfee, J. G. (2015). *Assessment in speech-language pathology: A resource manual* (5th edn.). Cengage Learning.

Tardif, T., Gelman, S. A., & Xu, F. (1999). Putting the "noun bias" in context: A comparison of English and Mandarin. *Child Development*, *70*(3), 620–635. https://doi.org/10.1111/1467-8624.00045

Tardif, T., Shatz, M., & Naigles, L. (1997). Caregiver speech and children's use of nouns versus verbs: A comparison of English, Italian, and Mandarin. *Journal of Child Language*, *24*(3), 535–565. https://doi.org/10.1017/S030500099700319X

Uccelli, P., Demir-Lira, Ö. E., Rowe, M. L., Levine, S., & Goldin-Meadow, S. (2019). Children's early decontextualized talk predicts academic language proficiency in midadolescence. *Child Development*, *90*(5), 1650–1663. https://doi.org/10.1111/cdev.13034

Vallotton, C., & Ayoub, C. (2011). Use your words: The role of language in the development of toddlers' self-regulation. *Early Childhood Research Quarterly*, *26*(2), 169–181. https://doi.org/10.1016/j.ecresq.2010.09.002

van der Maas, H. L. J., Dolan, C. V., Grasman, R. P. P. P., Wicherts, J. M., Huizenga, H. M., & Raijmakers, M. E. J. (2006). A dynamical model of general intelligence: The positive manifold of intelligence by mutualism. *Psychological Review*, *113*(4), 842–861. https://doi.org/10.1037/0033-295X.113.4.842

Vouloumanos, A., & Werker, J. F. (2004). Tuned to the signal: The privileged status of speech for young infants. *Developmental Science*, *7*(3), 270–276. https://doi.org/10.1111/j.1467-7687.2004.00345.x

Vygotsky, L. S. (1962). Thought and word. In (E. Hanfmann & G. Vakar Eds.), *Thought and language* (pp. 119–153). MIT Press.

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

Wade, M., Browne, D. T., Madigan, S., Plamondon, A., & Jenkins, J. M. (2014). Normal birth weight variation and children's neuropsychological functioning: Links between language, executive functioning, and theory of mind. *Journal of the International Neuropsychological Society*, *20*(9), 909–919. https://doi.org/10.1017/S1355617714000745

Weiland, C., Barata, M. C., & Yoshikawa, H. (2014). The co-occurring development of executive function skills and receptive vocabulary in preschool-aged children: A look at the direction of the developmental pathways. *Infant and Child Development*, *23*(1), 4–21. https://doi.org/10.1002/icd.1829

Werker, J. F., & Tees, R. C. (2002). Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior & Development*, *7*(1), 49–63. https://doi.org/10.1016/S0163-6383(84)80022-3

Whedon, M., Perry, N. B., Calkins, S. D., & Bell, M. A. (2018). Cardiac vagal regulation in infancy predicts executive function and social competence in preschool: Indirect effects through language. *Developmental Psychobiology*, *60*(5), 595–607. https://doi.org/10.1002/dev.21636

White, L. J., Alexander, A., & Greenfield, D. B. (2017). The relationship between executive functioning and language: Examining vocabulary, syntax, and language learning in preschoolers attending Head Start. *Journal of Experimental Child Psychology*, *164*, 16–31. https://doi.org/10.1016/j.jecp.2017.06.010

Wiebe, S. A., Espy, K. A., & Charak, D. (2008). Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. *Developmental Psychology*, *44*(2), 575–587. https://doi.org/10.1037/0012-1649.44.2.575

Wiebe, S. A., Lukowski, A. F., & Bauer, P. J. (2010). Sequence imitation and reaching measures of executive control: A longitudinal examination in the second year of life. *Developmental Neuropsychology*, *35*(5), 522–538. https://doi.org/10.1080/87565641.2010.494751

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

Willoughby, M. T., Magnus, B., Vernon-Feagans, L., & Blair, C. B., & Family Life Project Investigators. (2017). Developmental delays in executive function from 3 to 5 years of age predict kindergarten academic readiness. *Journal of Learning Disabilities*, *50*(4), 359–372. https://doi.org/10.1177/0022219415619754

Wolfe, C. D., & Bell, M. A. (2004). Working memory and inhibitory control in early childhood: Contributions from physiology, temperament, and language. *Developmental Psychobiology*, *44*(1), 68–83. https://doi.org/10.1002/dev.10152

Woodard, K., Pozzan, L., & Trueswell, J. C. (2016). Taking your own path: Individual differences in executive function and language processing skills in child learners. *Journal of Experimental Child Psychology*, *141*, 187–209. https://doi.org/10.1016/j.jecp.2015.08.005

Zelazo, P. D. (2006). The Dimensional Change Card Sort (DCCS): A method of assessing executive function in children. *Nature Protocols*, *1*(1), 297–301. https://doi.org/10.1038/nprot.2006.46

Zelazo, P. D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development*, *11*(1), 37–63. https://doi.org/10.1016/S0885-2014(96)90027-1

Zelazo, P. D., Müller, U., Frye, D., Marcovitch, S., Argitis, G., Boseovski, J., Chiang, J. K., Hongwanishkul, D., Schuster, B. V., & Sutherland, A. (2003). The development of executive function in early childhood. *Monographs of the Society for Research in Child Development*, *68*(3), vii–137. https://doi.org/10.1111/j.0037-976x.2003.00260.x

How to cite this article: Bruce, M., Savla, J., & Bell, M. A. (2023). From terrible twos to sassy sixes: The development of vocabulary and executive functioning across early childhood. *Developmental Science*, e13396. https://doi.org/10.1111/desc.13396