From Terrible Twos to Sassy Sixes: The Development of Vocabulary and Executive Functioning Across Early Childhood

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ABSTRACT

Early childhood marks a time when word learning is accompanied by rapid growth in the cognitive processes that underlie self-modulated and goal-directed behavior (i.e., executive functions (EF)). Although there is empirical evidence to support the association between EF and vocabulary development in childhood, inconsistent findings have been reported regarding the extent to which early EF abilities predict later vocabulary outcomes and vice versa. Thus, the first aim of the present study was to employ a stringent analytic approach to examining the longitudinal relations between EF and vocabulary across multiple waves in early childhood (i.e., at ages 2, 3, 4, and 6). Among the studies that have documented a link between children’s early and later EF/vocabulary skills, the underlying mechanism(s) that can account for this association have yet to be identified. As such, the second and third aims of this study were to investigate children’s private speech and visual attention skills as potential mediators of the hypothesized link between early and later EF/vocabulary. The results indicate that after controlling for maternal education, a unidirectional cross-lagged panel model best fit the data. That is, across all measurement waves, children’s vocabulary scores at one timepoint were positively predictive of their EF performance at the following timepoint. Although no evidence of mediation was detected, a significant and novel association emerged between children’s early vocabulary scores and their later private speech production. Moreover, this study was able to replicate the well-established link between visual attention and receptive vocabulary among a sample of older children.
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GENERAL AUDIENCE ABSTRACT

Across the first few years of life, young children are quickly learning to understand/say new words (vocabulary development) at the same time that they are improving upon their ability to create plans, solve problems, and control their thoughts/actions (executive functioning (EF) development). These early skills act as developmental “building blocks” because they play an essential role in shaping more complex abilities later in childhood and even adulthood. Given their importance, the first goal of this study was to examine whether children’s early abilities in one area are related to their later abilities in the other area at multiple ages across the early childhood period. For example, does vocabulary size at age 2 or age 3 relate to children’s EF scores at age 3 or age 4? The results show that at each age measured in this study, children’s early word knowledge predicted their later EF performance. The second goal of this study was to identify research-based, mediating variables in order to better understand why the expected association between vocabulary and EF exists in childhood. The results show that children with larger vocabularies at age 2 think out loud more when completing a difficult task at age 4, and that children who are skilled at finding requested objects when viewing a cluttered picture at age 4 have larger vocabularies at age 6. Collectively, these findings suggest that children’s language and cognitive skills are closely related starting in toddlerhood and continuing into the elementary school years.
DEDICATION

To all the women who cry when they’re angry.
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Chapter 1

1 Introduction

When considering the many skills acquired across the span of early childhood, language and executive functioning (EF) are among the earliest to emerge and they are foundational to children’s later academic achievement, social competence, and interpersonal problem-solving abilities (Blair & Razza, 2007; Longobardi et al., 2016; Moll et al., 2015; Sesma et al., 2009). It is not surprising then that the developmental literature has overwhelmingly provided evidence of a positive association between EF and verbal ability in early childhood (e.g., Carlson et al., 2005; Carlson et al., 2004; Fuhs & Day, 2011; Kuhn et al., 2014; Weiland et al., 2014; Wolfe & Bell, 2004). EF and language are similar in the sense that they are both multidimensional constructs that comprise of effortful and interrelated components. Although developmental research illustrates that EF is best represented as a unitary construct in early childhood (Wiebe et al., 2008; 2011), language can be divided into three separate domains (i.e., form, content, and use) that converge in the successful comprehension and/or production of communicative messages (Bloom & Lahey, 1978). Vocabulary development falls within the language content domain, and it is of particular interest to developmental researchers both because it begins in infancy and extends across early childhood, and because it appears to play a role in understanding and completing goal-oriented cognitive tasks (Fenson et al., 1994; Vygotsky, 1978). Likewise, EF has its roots in infancy and may enable children to focus on linguistic input in the pursuit of early vocabulary building (Blankson et al., 2011). Given the similarities in the developmental trajectory of these seemingly interrelated processes, the current study focuses specifically on the association between early childhood EF and vocabulary development.
Wolfe and Bell (2004) show that preschool children with larger vocabularies exhibit
greater concurrent working memory and inhibitory control skills, and Kuhn et al. (2014)
illustrate a developmental pathway between infant communicative gesturing and preschool EF
through vocabulary size in toddlerhood. This link between EF and vocabulary even extends
across studies with demographically diverse and/or atypically developing child populations
(Figueras et al., 2008; Harvey & Miller, 2017; Kapa & Erikson, 2020; White et al., 2017), as
well as among studies measuring vocabulary purely as a covariate (Bock et al., 2015; Cuevas &
Bell, 2014; Kraybill et al., 2019; McAlister & Peterson, 2006). Nonetheless, inconsistent
findings have been reported in the literature as some researchers have failed to replicate this
significant association between EF and vocabulary in childhood (Cameron et al., 2012; Chung &
McBride-Chang, 2011; Gooch et al., 2016). Even among studies that do report a significant and
longitudinal relation between children’s early and later EF/vocabulary abilities, the
developmental processes that may account for this link have been under-researched and therefore
are not well understood. As a result, the global objective of my dissertation research is to apply a
rigorous analytic approach to examining the longitudinal relations between EF and vocabulary,
and to examine the mechanisms that may underlie these predictive associations in early
childhood.

1.1 Early Childhood Vocabulary Development

Vocabulary development is inherently socially communicative, meaning that the ability
to comprehend (i.e., receptive) and eventually produce (i.e., expressive) words is dependent upon
early exposure to speech from a mature linguistic partner. Even very young infants are sensitive
to and captivated by the linguistic information present in their environment, despite their
inability to derive its meaning (Cooper & Aslin, 1990). For example, infants under 6- to 8-
months of age can detect auditory, consonant-vowel speech contrasts in both their native and non-native languages (Werker & Tees, 2002). Werker and Tees (2002) show that monolingual, English-learning 6-month-olds are capable of perceiving both the English /ba/-/da/ contrast and the [novel] Hindi /ṭa/-/ta/ contrast. Superior phonetic perception in early infancy is predictive of vocabulary outcomes in toddlerhood (Tsao et al., 2004), and infants experience a marked decline in their ability to detect non-native phonemic contrasts toward the end of their first year (Kuhl et al., 2006; Werker & Tees, 2002). This early preference for and sensitivity to oral speech is vital to cueing infants into the phonetic properties of the novel words that they will eventually recognize and even produce later in development.

Across the first postnatal year, infants also commonly engage in prelinguistic communication as a precursor to word production (Morgan & Wren, 2018). Very young infants often produce “protophones” (i.e., speech-like vocalizations such as high-pitched squeals or vowel sounds) and make the transition to babbling starting around 6-months of age (i.e., producing fully-formed, consonant-vowel syllables such as “dada” or “baba”; Lee et al., 2018). Interestingly, Choi et al. (2019) report that obstructing preverbal infants’ oral-motor movements interferes with their discrimination of select auditory speech contrasts. Thus, prelinguistic communication in infancy appears to heavily influence early speech perception as well as precede later word production.

Early word knowledge and speech production is promoted through repeated exposure to words across a variety of contexts (Hart & Risley 1995; Horst, 2013). For example, Goldstein and Schwade (2008) report that infants frequently restructure the phonologic pattern of their prelinguistic vocalizations to mirror that of their mothers’ speech after receiving contingent feedback from her during parent-child interactions. Researchers report differences in the
emergence of receptive and expressive language, despite being strongly correlated throughout early childhood. Many children are comprehending words by 9-months of age but do not produce their first recognizable words until the end of their first year (Fenson et al., 1994). Children’s first spoken words tend to be nouns (and they are commonly names for people), although there’s evidence that the strength of this early “noun bias” may vary as a function of cultural context as well as study methodology (Alcock, 2017). In contrast, children’s early receptive vocabularies tend to include a comparatively larger proportion of verbs (Bates et al., 1979). From infancy, vocabulary growth is slow during the first half of children’s second postnatal year, yet it increases rapidly starting around 18-months and continues well into the preschool/kindergarten years (Fenson et al., 1994). In part, this trend may reflect two-year-olds’ drastically improved ability to utilize social information (e.g., eye gaze) in discerning ambiguous word-referent pairings in comparison to infants (Golinkoff & Hirsh-Pasek, 2006). This rapid vocabulary expansion in toddlerhood enables children to begin to understand and use language in an increasingly complex manner. For instance, despite the unique and complicated way in which pronouns can be used as substitutes for nouns, preschoolers demonstrate a strong understanding of how first- and second-person pronouns operate (Campbell et al., 2000). Taken together, steady progression in speech perception and prelinguistic vocal production in early infancy gives way for the extensive vocabulary growth that begins near the end of the first postnatal year and continues across the early childhood period.

1.2 Early Childhood Executive Functioning

Executive functions (EF) are frequently described as effortful, top-down cognitive processes that allow individuals to engage in goal-directed behaviors such as planning, problem-solving, and monitoring/adjusting one’s behavior (Diamond, 2013). Maturational changes to the
prefrontal cortex result in the emergence of EF in late infancy and promote improvements in EF across early childhood (Diamond, 2002; Fiske & Holmboe, 2019). The early childhood years are of focus in much of the developmental literature because they mark the transition from infancy whereby children are beginning to be expected to modulate their own behavior, often in contexts outside the home. For instance, school-aged children rely heavily on EFs to successfully perform tasks such as raising their hand and waiting to be called on, transitioning from free-play to a structured activity, and following a list of instructions to “pack up your things, push in your chair, and line up by the door.”

EF is thought to comprise of three core components: Inhibitory control (the ability to exert control over one’s attention/thoughts/behaviors to do what is contextually appropriate or necessary), working memory/updating (the ability to hold information in the mind and manipulate it), and cognitive flexibility/shifting (the ability to switch between tasks/mental states and adjust to changing demands; Bell & Garcia Meza, 2020; Diamond, 2013). There is a longstanding debate about how EF is operationalized and measured in childhood. Of particular interest to researchers is whether EF represents a unitary construct or a constellation of independent components, as well as the degree to which the factor structure of EF is stable across development. Research with adults using confirmatory factor analysis (CFA) has identified a three-factor model comprised of inhibition, updating, and shifting (Miyake et al., 2000). That is, these factors represent distinct yet interrelated components that may be differentially employed based on the task at hand. This factor structure has been replicated in research with older children ages 8 to 13 (Lehto et al., 2003). However, the early childhood literature points to a more integrative framework for studying EF where the best-fitting model is a 1-factor model starting around 3-years of age (Garon et al., 2008; Wiebe et al., 2008; 2011).
EF emerges in infancy and develops swiftly in childhood (Espy et al., 2001; Fatzer & Roebers, 2012; Garon et al., 2008). Because there are a limited number of infant EF tasks available to researchers, much of the literature to date has focused on the A-not-B task (Bell, 2012; Diamond et al., 1997). This task is one of many multilocation search tasks that requires infants to inhibit the urge to search for an object in a familiar location (location A) having observed that it was hidden in a new location (location B). Performance on the A-not-B task improves significantly with age, such that longer delays between hiding and searching are needed to produce the error with older infants.

In contrast to infants, children exhibit more advanced motor and linguistic skills which means that there are a greater number of tasks appropriate for assessing EF in this age range. Starting in toddlerhood, dramatic improvements in inhibitory control have been reported across delay-of-gratification and conflict inhibition tasks, and these improvements are predictive of later developmental outcomes, even extending into adulthood (Carlson, 2005; Diamond, 2013; Joyce et al., 2016). Working memory abilities also appear early in development and by toddlerhood, most children are able to successfully complete working memory tasks such the spinning/stationary pots task (Diamond et al., 1997; Miller & Marcovitch, 2015; Wiebe et al., 2010). However, the ability to hold multiple items in the mind and/or complete complex mental operations develops much slower across childhood. Although EF tasks are often referred to as either an inhibitory control or working memory task, Diamond (2013) argues that these cognitive processes are closely related and frequently operate in tandem. For instance, when inhibiting the urge to grab an attractive toy from a peer, a child must hold in the mind their goal (e.g., playing together with a friend) and a related series of operations (e.g., “first I have to wait 5 minutes and then I can ask if they are done with the toy”). Likewise, a child going through their morning
routine needs to inhibit the urge to shift their focus to the TV on in the background in order to get ready for school on time. Finally, cognitive flexibility develops relatively later in early childhood as it is thought to build upon rudimentary working memory and inhibitory control skills (Blakey et al., 2016; Diamond et al., 2013). On the Dimensional Change Card Sort Task, a frequently administered cognitive flexibility task, toddlers can flawlessly sort cards by either the color or shape rule but experience significant difficulty when attempting to switch between rules. By the time children reach the kindergarten years, however, most are able to flexibility switch between sorting criteria (Diamond, 2013).

1.3 The Longitudinal Link Between Vocabulary and Executive Functioning

There is considerable evidence of an association between vocabulary and EF in early childhood. That is, vocabulary appears to be positively related to EF in research across demographically diverse samples of toddlers and preschoolers (Panesi & Morra, 2021; Šimleša et al., 2017; White et al., 2017). Clinical and developmental researchers also report that deficits in one domain (i.e., executive functioning or language more broadly) influence performance in the other. For instance, children diagnosed with Selective Language Impairment (SLI) exhibit poorer performance on working memory, inhibitory control, and cognitive flexibility tasks in comparison to children without a language impairment (Henry et al., 2012; Vissers et al., 2015). Even among neurotypical samples, children’s performance on complex working memory tasks worsens when they are asked to simultaneously complete a verbal (but not motor) task (Fatzer & Roebers, 2012). What remains unclear from these concurrent findings, however, is how this association between EF and vocabulary emerges and unfolds over time. In other words, does early vocabulary acquisition facilitate the development of EF, or are rudimentary EF skills integral to later word learning in childhood?
To date, inconsistent findings have been reported regarding the extent to which vocabulary and EF are longitudinally related in early childhood. For example, multiple researchers report that children’s vocabulary size at age 3 was predictive of their EF performance during the preschool/kindergarten years (Daneri et al., 2019; Müller et al., 2012; Whedon et al., 2018). In contrast, Carlson et al. (2004) report that children’s vocabulary size at age 2 was not predictive of their EF outcomes a year later after controlling for children’s age 2 EF skills. Similarly, while some researchers report that preschool EF is predictive of children’s later vocabulary outcomes (Fuhs et al., 2015; McClelland et al., 2014; Willoughby et al., 2017), others illustrate that this predictive link is not significant after controlling for children’s initial vocabulary size (Cameron et al., 2012; McClelland et al., 2007; Ponitz et al., 2009). Finally, discrepancies have also been reported among the handful of studies examining bidirectional relations between EF and vocabulary in childhood. Both Fuhs et al. (2014) and Schmitt et al. (2019) demonstrate that vocabulary size at the start of preschool was predictive of children’s EF outcomes by the end of preschool, and that preschoolers’ EF scores at the start of the year were predictive of their vocabulary scores by the end of the preschool year. However, the majority of studies have failed to find evidence of a bidirectional association between vocabulary and EF across early childhood; either because only a unidirectional link was detected (Fuhs & Day, 2011; Petersen et al., 2014; Weiland et al., 2014) or because neither EF nor vocabulary were predictive of children’s respective outcomes later in childhood (Chung & McBride-Change, 2011; Gooch et al., 2016).

Some of the discrepancies reported in the longitudinal literature may be due to the various methodological and analytic differences that exist across research studies. In part, the positive correlation reported between childhood vocabulary and EF may be driven by the overlap
in tasks’ verbal demands (Kaushanskaya et al., 2017). Schonberg et al. (2018) report that alterations to the verbal instructions for a reverse categorization EF task significantly impacted two-year-olds’ performance on that task. That is, when the experimenters used fewer dimension-related words in their explanation of how to complete the task, toddlers’ performance improved considerably. Thus, the extent to which children’s early skills are predictive of their EF/vocabulary outcomes later in childhood may be affected by studies’ use of verbally demanding EF tasks.

Comparing and consolidating findings from the literature is made even more difficult when considering the limited agreement among researchers as to what various EF tasks are actually measuring (Carlson, 2005; Fuhs & Day, 2011). For example, the Dimensional Change Card Sort task has been conceptualized as measuring attentional flexibility (Fuhs et al., 2015), task-shifting (Kaushanskaya et al., 2017) or even multiple cognitive domains (e.g., attention, working memory, and inhibitory control; Watson & Bell, 2013). Yet, without conceptual clarity as to what underlying skills EF tasks are supposedly tapping into in childhood, it is unclear whether EF tasks are interchangeable and can be selected at random across studies with little to no effect on the results. Finding evidence for a 2-factor model with preschool children, Miller et al. (2012) argue that the factor structure of EF in childhood may be influenced in part by task selection. Thus, there is a need for further research utilizing latent factor analysis with a clear rationale behind EF task selection to better understand the factor structure of EF over time, especially as it relates to early childhood vocabulary development.

Of course, it is also possible that the predictive association between vocabulary and EF differs between late infancy/toddlerhood and the preschool/kindergarten years. A greater number of longitudinal studies report that children’s vocabulary size in the first three years of life
significantly predicts later EF in comparison to number of studies supporting the inverse pathway (i.e., that infant/toddler EF predicts later vocabulary outcomes; Kuhn et al., 2014; Miller & Marcovitch, 2015; Petersen et al., 2014; Whedon et al. 2018). In contrast, research with preschoolers suggests that both children’s verbal and EF abilities predict their respective scores later in the academic year (Fuhs & Day, 2011; McClelland et al., 2014; Schmitt et al., 2019). Although far fewer studies have assessed children’s EF abilities prior to the preschool years in comparison to verbal skill, it is possible that some of the disagreement reported in the literature may be due to genuine differences in the developmental trajectory of these processes as a function of child age.

Furthermore, even though longitudinal research allows for the examination of developmental growth and change over time, many of the existing developmental studies have relied on two-wave study designs (Carlson et al., 2004; Fuhs et al., 2015; McClelland et al., 2007; Miller & Marcovitch, 2015; Müller et al., 2012; Schmitt et al., 2019; Wade et al., 2014; Weiland et al., 2014). This in turn makes it difficult to disentangle actual change from measurement error and significantly restricts the assessment of development over time (Ployhart & MacKenzie, 2015). As a result, additional multi-wave research starting in toddlerhood (when vocabulary/EF skills are rapidly developing) and extending to the elementary school years is needed to better clarify whether the relation between EF and vocabulary differs as a function of age in early childhood.

1.4 Private Speech and Visual Attention in Early Childhood

If children’s vocabulary/EF abilities in toddlerhood are predictive of their cognitive-linguistic outcomes during the elementary school years, then a major question for developmental researchers is what are the underlying mechanisms that can account for these longitudinal
relations in early childhood. One theory is that early vocabulary size may be essential to the successful execution of goal-oriented activities early in life via the emergence of private speech during the preschool years. From a Vygotskian perspective, private speech can be defined as overt speech directed to the self (1962, 1978). In contrast to Piaget & Inhelder’s (1969) view of self-directed speech as a reflection of young children’s cognitive immaturity, Vygotsky 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-directing thought/action, which become internalized over the course of development (Vallotton & Ayoub, 2011).

Overt private speech emerges as a self-regulatory tool in toddlerhood and becomes increasingly frequent, task-relevant, and partially internalized during the preschool years (Winsler et al., 2000; 2009). Indeed, Winsler et al. (1997) report that when presented with a difficult cognitive task, a majority of preschoolers emitted some form of private speech, where greater task-relevant private speech was associated with superior task performance. Research investigating the association between private speech and early childhood cognition reveals that both the content and amount of private speech used by preschoolers is associated with preschool performance of tasks that require planning, directing, and problem-solving skills (Azmitia, 1992; Behrend et al., 1989; Mulvihill et al., 2021). For example, Mulvihill and colleagues (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. Furthermore, Montero and de Dios (2006) report a significant interaction between private speech and task difficulty, whereby private speech frequency/content was related to preschoolers’ performance when presented with a difficult
puzzle task. Thus, children’s engagement in private speech appears to play an important role in the successful execution of concurrent effortful and goal-oriented action, especially in circumstances where the cognitive demands are high.

An alternative and equally plausible explanation is that rudimentary EF abilities may enable children to direct their attention to language-relevant information in their environment and inhibit shifting to salient yet irrelevant, distracting events in the pursuit of vocabulary development (Blankson et al., 2011). Previous research highlights the importance of visual attention with respect for word learning as longer durations of visual attention to labeled objects are associated with greater comprehension of newly acquired words in early childhood (Macroy-Higgins & Montemarano, 2016). However, word learning naturally occurs in the context of environments that contain a multitude of sights and sounds competing for one’s attention (Godwin et al., 2018). For example, to acquire novel linguistic information, a young child reading a book with their mother needs to fixate their attention toward the illustrated pictures being talked about and inhibit shifting their attention toward irrelevant background distractors, such as a TV or a household pet.

Previous reports find that volitional control over the orienting attention network emerges during the first postnatal year, where even infants are capable of orienting attention to salient or novel stimuli in their environment that may afford opportunities to receive linguistic input (Johnson, 1990; Posner & Rothbart, 2013). However, the ability to selectively orient and maintain visual focus during moments of high attention competition develops more gradually in childhood (Colombo, 2001; Colombo & Cheatham, 2006). For example, Dixon et al. (2006) report that toddlers’ performance on a word-learning task was adversely affected by environmental distractors; although, this effect was moderated by toddlers’ concurrent
attentional skills. Research with preschoolers highlights a similar finding as distractors are highly disruptive to preschoolers’ task performance, especially when they are presented continuously as opposed to intermittently (Fisher et al., 2014; Kannass & Colombo, 2006; Kannass et al., 2010; Wetzel et al., 2019). However, younger as opposed to older preschoolers seem particularly susceptible to interference caused by environmental distractors, which illustrates an interesting trend across the preschool years that bears some resemblance to the developmental trajectory of inhibitory control (Diamond, 2013; Diamond & Taylor, 1996). Indeed, inhibitory skill in toddlerhood has been found to predict attention regulation during middle childhood, as assessed via behavioral observations and maternal report (Jaekel et al., 2016). Thus, children’s early EF abilities may influence their ability to appropriately shift and maintain visual attention, which in turn may promote early childhood vocabulary learning.

The developmental literature has yet to investigate whether private speech or visual attention during the preschool years mediates the previously documented longitudinal association between children’s early and later vocabulary and EF abilities. Of course, these proposed mediational pathways are not mutually exclusive. That is, if bidirectional links are uncovered between early EF/vocabulary and children’s later outcomes, it’s possible that vocabulary size in toddlerhood predicts later EF via preschool private speech and that toddler EF is predictive of vocabulary outcomes later in early childhood via preschool visual attention. Given the importance of understanding the underlying mechanisms that facilitate cognitive-linguistic development with respect for early childhood intervention, an investigation into whether vocabulary/EF skills in toddlerhood influence child outcomes during the elementary school years via preschool private speech and/or visual attention is warranted.
1.5 Current Study

The objective of my dissertation research is to evaluate the association between vocabulary and EF across early childhood (Aim #1), as well as to test two potential mechanisms that may account for the predictive link between early vocabulary/EF and children’s later outcomes based on the developmental literature (Aims #2 and #3).

Although there is empirical evidence to support a link between these two processes in childhood, inconsistent research findings have been reported regarding the extent to which early EF performance predicts later vocabulary size and vice versa. In part, some disagreement in the literature may be due to diversity in the study designs (e.g., the age of participants recruited or the number of data collection waves) and analytic strategies (e.g., whether children’s baseline scores are measured and if/how an EF composite score is derived) adopted by developmental researchers. Thus, replication research utilizing a rigorous methodological approach is necessary to better understand the nature of the association between EF and vocabulary.

**Aim #1:** The first aim of my dissertation study is therefore to examine the longitudinal relation between vocabulary and EF using structural equation modeling in a large sample of children starting in toddlerhood when skills are emerging (age 2) and continuing up to the beginning of the elementary school years (ages 3, 4, and 6). Based on the existing literature, the following hypotheses were made:

1a) A unitary factor model of EF will fit the data at each age.

1b) Early vocabulary will predict later EF across developmental timepoints (e.g., age 2 vocabulary size will predict age 3 EF, age 3 vocabulary size will predict age 4 EF, etc.)

1c) Early EF will predict later vocabulary outcomes across developmental timepoints (e.g., age 2 EF will predict age 3 vocabulary, age 3 EF will predict age 4 vocabulary, etc.)
Despite empirical reports that vocabulary is positively related to EF in early childhood, the underlying mechanism responsible for this predictive association remains unclear. It has been proposed that language via private speech may enable young children to engage in higher order cognitive operations. Thus, having a large vocabulary very early in life may provide children with the tools necessary to independently manipulate and direct their thoughts/actions in the pursuit of effortful, goal-directed behavior. Although previous research has uncovered links between private speech and self-regulation, there is an absence of literature exploring whether early vocabulary influences EF later in childhood through children’s use of private speech.

**Aim #2:** My study’s second aim is to examine whether vocabulary size in toddlerhood (age 2) predicts EF ability during the elementary school years (age 6) via children’s engagement in private speech during the preschool years (age 4). Based on the existing literature, the following hypotheses were made:

- **2a)** Age 4 private speech will be positively correlated with age 2 vocabulary and age 6 EF.
- **2b)** Age 2 vocabulary will directly influence age 6 EF.
- **2c)** Age 2 vocabulary will indirectly influence age 6 EF through age 4 private speech.

Finally, researchers have also demonstrated that early EF is positively related to later vocabulary outcomes in childhood. In this sense, children’s rudimentary EF skills may influence their ability shift and/or maintain their attention to audiovisual linguistic information present in their environment, which in turn predicts childhood word learning and production. Research conducted with infants has overwhelming highlighted clear links between attention and vocabulary development, and between attention and EF performance. However, considerably less research has evaluated these relations longitudinally across early childhood and whether early EF indirectly influences later vocabulary outcomes through child visual attention.
Aim #3: The third aim of my study is to examine whether EF ability in toddlerhood (age 2) predicts children’s vocabulary size during the elementary school years (age 6) via children’s visual attention skills during the preschool years (age 4). Based on the existing literature, the following hypotheses were made:

3a) Age 4 visual attention will be positively correlated with age 2 EF and age 6 vocabulary.

3b) Age 2 EF will directly influence age 6 vocabulary.

3c) Age 2 EF will indirectly influence age 6 vocabulary through age 4 visual attention.
Chapter 2

2 Method

2.1 Participants

Participants are part of a multi-wave 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) using mailing lists, media advertisements, flyers, and word of mouth. In this larger longitudinal study, a total of 410 children were recruited in infancy and were invited back to the lab at various timepoints across childhood (e.g., at 2, 3, 4, and 6 years of age; see Table 1 for sample demographic information). Children were recruited as three cohorts: Blacksburg cohort 1 (n = 106), Blacksburg cohort 2 (n = 105); Greensboro cohort 3 (n = 199). Cohort 1 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. Additional details regarding attrition and the sample size at each data collection wave are discussed below.

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 p > .05).

Age 3 Lab Visit
Of the 410 children recruited as infants, 115 children did not return for the age 3 lab visit \((n_{\text{age}\_3} = 295; 145 \text{ girls})\). 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 executive functioning 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 for child sex, child race, or maternal education (all \(p > .05\)).

**Age 4 Lab Visit**

Of the 410 children recruited as infants, 140 children did not return for the age 4 lab visit \((n_{\text{age}\_4} = 270; 128 \text{ girls})\). 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 \(p > .05\)).

**Age 6 Lab Visit**

Of the 410 children recruited as infants, 216 children did not return for the age 6 lab visit \((n_{\text{age}\_6} = 194; 94 \text{ girls})\). Because of the funding 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 \((216 – 106)\), 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. 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 \(p > .05\)).

### 2.2 General Procedure

Data were collected at both research locations using identical protocols. Research assistants at both institutions were trained by Dr. Martha Ann Bell. 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 behavioral EF data coded by the Greensboro team.

Upon arrival to the research lab, a research assistant greeted families and explained both the study and lab procedures. Informed consent was obtained from mothers at each visit and verbal assent was obtained from children starting at age 2. Demographic information was collected in infancy when children were initially recruited to participate in the larger longitudinal 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). At the age 3 and age 4 lab visit, children also participated in a visual search task and a solitary puzzle task. Given the aforementioned links between vocabulary/EF and child attention/private speech during the preschool years, only age 4 visual attention (derived from the visual search task) and private speech (derived from the puzzle task) data is included in the present study. Each session was recorded for offline behavioral coding as well as reliability coding. Study procedures for the larger longitudinal 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 larger longitudinal 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 vocabulary), 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).

**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.

**Peabody Picture Vocabulary Test (PPVT; Ages 3, 4, and 6)**

The 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 pictures and were instructed to select the picture 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.

2.4 Executive Functioning Measures

Children’s EF was assessed at ages 2, 3, 4, and 6 using a battery of developmentally-appropriate behavioral tasks. The EF tasks detailed below were purposely selected for the current study because these tasks: a) are established measures of early childhood EF in the developmental literature; 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); c) are well-suited for the planned analyses (i.e., the tasks produce continuous data which is optimal for Confirmatory Factor Analysis; Fuhs & Day, 2011).

Interrater reliability scoring was accomplished on a least 18% of the sample and the percent agreement across all tasks listed below was good to excellent (Intraclass correlation coefficients (ICC) ≥ .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).

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.
**Crayon Delay (Age 2)**

The Crayon Delay task 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 to not 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.

**Dimensional Change Card Sort (DCCS; Ages 2, 3, 4, and 6)**

The 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 administer 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) border responses at age 6.

**Day/Night (Age 3)**

The Day/Night task 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 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. The variable of interest was the proportion of points earned across all test trials.

**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. 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.

**Gift Peek (Age 4)**

The Gift Peek task 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.

**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 reaction times and therefore greater task performance.

**2.5 Private Speech Measure**

**Frustrating Puzzle (Age 4)**

As a contribution to the CAP Lab’s archival dataset, children’s private speech was coded during a 2-minute puzzle task, which was administered in the larger longitudinal study as a measure of early emotion regulation (Perry et al., 2018). During this task, children were instructed to work on an animal themed puzzle by themselves while their mother and a research assistant pretended to be busy. Children were intentionally given a puzzle that was too difficult for their developmental age and no child successfully completed the task. Children’s private speech during the frustrating puzzle task was transcribed and coded as mature or immature based on the audibility and content (i.e., task relevance) of children’s self-directed utterances, in accordance with the coding scheme developed by Whedon et al. (2021) based on Berk (1986) and Winsler et al.’s (2005) existing guidelines.
Immature private speech can be defined as utterances that are self-stimulatory and/or task irrelevant. Utterances containing wordplay/repetition (e.g., “chair, ch-, ch-, ch-, chair”) or statements that are unrelated to the task (e.g., “I like animal crackers”) are therefore classified as immature. In contrast, mature private speech can be defined as utterances containing either task-relevant statements or partially-internalized speech (e.g., quiet muttering to the self in the context of sorting puzzle pieces). Thus, task relevant utterances containing questions (e.g., “where is that corner?”), describing current/planned actions (e.g., “I need to find the edge pieces”), or providing self-feedback (e.g., “no, I can’t put it there”) are classified as mature. The variable of interest was the proportion of mature private speech. Interrater reliability scoring was competed for 25% of the sample and acceptable agreement was achieved (ICC = .82).

2.6 Visual Attention Measure

*Bears task (Age 4)*

This 2-minute task is a modified version of the visual attention subtest on the NEPSY: A Developmental Neuropsychological Assessment (Espy et al., 2004; Korkman et al., 1998). Children were required to point to items (i.e., bears; 11 in total) that matched the target item on a laminated page that contained both distractor and target items. The variable of interest was the efficiency score, which represents the proportion of target responses. Interrater reliability scoring was competed for 28% of the sample and acceptable agreement was achieved (ICC = .94).

2.7 Covariate Measures

Information regarding child sex (1= girl and 0 = boy) and maternal education (1 = college education and 0 = no college education) was also gathered using the CAP Lab general information questionnaire as these variables have well-documented connections to child language and cognition in the previous literature (Bornstein & Cote, 2005; Hoff, 2003).
2.8 Analytic Plan

Descriptive statistics were generated for the primary variables of interest using IBM SPSS software (Version 22; see Table 2 and Appendix B). 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 = 13) that were ± 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).

Specifically, the variables and total number of values that were Winsorized are as follows: PPVT at age 4 (> +3SD = 1); Forward Digit Span at age 4 (> +3SD = 1); Day/Night at age 4 (< -3SD = 3); Bears at age 4 (< -3SD = 3); Number Stroop – Reaction Time (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). Power guidelines by MacCallum et al. (1996) indicated that the most complex model would require a minimum sample of 200 children to provide acceptable power to detect model fit (power ≥ .80; α = .05). As expected, correlation coefficients indicated that the covariates, child sex and maternal education, were significantly related to study variables across data collection waves (Table 4).

The hypothesized models were tested via structural equation modeling (SEM) in Mplus (Version 8; Muthén & Muthén, 2017) with full information maximum likelihood (FIML) to account for missing data. This estimation approach utilizes all available data and results in less biased estimates and standard errors in comparison to other missing data techniques, such as listwise deletion (Enders, 2001). Inferential and descriptive indices of model fit were calculated: Chi-square ($\chi^2$) test, root mean square error of approximation (RMSEA < .08; MacCallum et al., 1996), and confirmatory fit index (CFI > .90; Hu & Bentler, 1999). Analyses were conducted in
three blocks. First, the measurement structure of child EF at ages 2, 3, 4, and 6 was examined. Next, a structural model was generated to test the hypothesized relations between vocabulary and EF across data collection waves. Finally, two mediation models were tested to identify potential mechanisms underlying the hypothesized association between age 2 and age 6 vocabulary/EF. Analytic strategies specific to each study aim and hypothesis are detailed below.

**Aim #1, Hypothesis A**

The developmental literature suggests that EF in early childhood represents a unitary construct and as a result, the best-fitting model is a 1-factor model (Wiebe et al., 2008; 2011). Thus, Confirmatory Factor Analysis (CFA) was used to fit a latent construct of EF as a 1-factor model at ages 2, 3, 4 and 6 (see Figure 1 for the conceptual, measurement model diagram). A unidimensional model was specified at each data collection wave wherein three observed variables were loaded onto the latent EF factor (given the risk of specification error in models with two indicators; Kline, 2011). The factor loadings were inspected and were considered acceptable if ≥ .45 (Hair et al., 2010). Although satisfactory model fit was achieved, weak factor loadings were detected in the initial measurement model (Table 5). As such, additional measurement models were specified where a) substitutions were made to the manifest variables (i.e., different EF tasks were included in the CFAs) and/or b) the error terms of repeated tasks were allowed to correlate across timepoints. Despite modest improvements as a result of these modifications, the factor loadings at each timepoint did not meet the minimum acceptable criteria.

Because the factor loadings were weak and composite values of latent constructs are more reliable than single EF assessments (Carlson et al., 2004), a composite EF score was generated for each child at ages 2, 3, 4, and 6 to be used in all of the analyses that followed.
Composite values were created at each age using the three EF tasks from the best-loading measurement model by standardizing and averaging children’s individual EF task scores. If a child was missing data for one of the three tasks, their scores on the other two tasks were averaged and standardized to create the composite EF value at that age in order to maximize statistical power. Likewise, standardized individual task scores were used in place of a composite EF value in the event that a child was missing data for two of the three tasks.

**Aim #1, Hypotheses B & C**

The longitudinal associations between EF and vocabulary were analyzed using an autoregressive cross-lagged panel design with four waves of data (ages 2, 3, 4 and 6; see Figure 1 for the conceptual, structural model diagram). 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). I planned on analyzing two models, one with and one without the covariates (child sex and maternal education) entered.

**Aim #2, Hypotheses A-C**

A basic mediation model (Hayes, 2013) was analyzed to test whether preschool private speech mediates the hypothesized association between vocabulary size in toddlerhood and children’s EF during the early elementary school years (see Figure 2 for the conceptual, mediation model diagram). The model included direct paths (a) from age 2 vocabulary to age 4 private speech, (b) from age 4 private speech to age 6 EF, and (c) from age 2 vocabulary to age 6 EF. An indirect path was also estimated from age 2 vocabulary to age 6 EF through age 4 private speech.

**Aim #3, Hypotheses A-C**
Similar to the aim described above, a second basic mediation model was conducted to evaluate whether preschool visual attention mediates the hypothesized association between EF ability in toddlerhood and children’s vocabulary size during the early elementary school years (see Figure 2 for the conceptual, mediation model diagram). The model included direct paths (a) from age 2 EF to age 4 visual attention, (b) from age 4 visual attention to age 6 vocabulary, and (c) from age 2 EF to age 6 vocabulary. An indirect path was also estimated from age 2 EF to age 6 vocabulary through age 4 visual attention.
Chapter 3

3 Results

3.1 Bivariate Correlations

Correlations were first calculated between the primary study variables: Vocabulary, EF (individual task scores and composite scores), private speech, and visual attention (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 .31 – .77 (all \( p < .01 \)). Children’s EF composite scores were also positively intercorrelated across data collection waves (ranging from .21 – .30; all \( p < .01 \)), with the exception of age 3 and age 6 EF which was not significantly correlated, \( r = .07, p = .37 \). Preschool private speech was positively correlated with children’s vocabulary scores at ages 2, 4, and 6 (\( r = .18, .13, .13 \), all \( p < .05 \)), and with preschoolers’ concurrent EF performance at age 4, \( r = .15, p = .02 \). By comparison, preschool visual attention was positively related to children’s vocabulary scores across all ages (2, 3, 4, and 6) \( (r = .16, .15, .19, .17 \text{ respectively, all } p < .05) \) and to children’s EF composite values at age 4, \( r = .22, p < .01 \), and at age 6, \( r = .15, p = .05 \).

Correlations were also examined between the primary study variables and the covariates: Child sex and maternal education (Table 4). Child sex was significantly correlated with children’s vocabulary scores at age 2, \( r = .17, p < .01 \), and age 3, \( r = .12, p = .05 \). 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 not related to children’s composite EF scores. Across all ages (2, 3, 4, and 6), maternal education was significantly correlated with children’s vocabulary scores \( (r = .15, .33, .29, .27 \text{ respectively, all } p < .01) \) as well as with children’s composite EF scores \( (r = .17, .20, .29, .17 \text{ respectively, all } p < .05) \). Given these significant
associations, both child sex and maternal education were controlled for in the longitudinal analyses described below.

### 3.2 Confirmatory Factor Analysis

#### Initial Measurement Model

The initial measurement model showed good fit, $\chi^2(48) = 60.06$, $p = 0.11$; RMSEA = 0.03 (90% CI = 0.00 – 0.05); CFI = 0.90. All of the manifest variables loaded significantly on their respective latent EF factor (all $p < .05$), yet many of the factor loadings were small and did not meet the set criteria of $\geq .45$ (Table 5).

#### Best-Loading Measurement Model

The measurement model that exhibited the best factor loadings showed mediocre model fit, $\chi^2(47) = 81.92$, $p < .01$; RMSEA = 0.05 (90% CI = 0.03 – 0.06); CFI = 0.82. Note that a df was lost because the age 3 and age 4 FDS error terms were allowed to covary. All of the manifest variables once again loaded significantly on the latent EF factors (all $p < .01$). However, several of the factor loadings across all timepoints were still relatively small, despite the adjustments made to the measurement model (Table 5).

### 3.3 Autoregressive Cross-lagged Panel Modeling

#### 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 entered (Model A; Figure 3) fit the data well, $\chi^2(12) = 41.32$, $p < .001$; RMSEA = 0.08 (90% CI = 0.06 – 0.11); CFI = 0.94.

**Autoregressive pathways.** As anticipated, the standardized coefficients for the autoregressive pathways of EF (ranging from .17 to .21) and vocabulary (ranging from .32 to
.78) were all significant (all p < .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.** Across all timepoints measured, children’s early vocabulary scores significantly predicted their subsequent EF scores. That is, age 2 vocabulary predicted age 3 EF, \( b = 0.30, SE = 0.06, p < .001 \), age 3 vocabulary predicted age 4 EF, \( b = 0.30, SE = 0.06, p < .001 \), and age 4 vocabulary predicted age 6 EF, \( b = 0.17, SE = 0.08, p = 0.034 \). In contrast, only children’s EF performance at age 2 was significantly predictive of their age 3 vocabulary, \( b = 0.14, SE = 0.06, p = .004 \).

**Residual correlations.** Concurrent correlations between EF and vocabulary were significant at age 2, \( b = 0.24, SE = 0.06, p = 0.002 \), age 3, \( b = 0.18, SE = 0.06, p = 0.002 \), and age 6, \( b = 0.32, SE = 0.07, p < .001 \).

**Panel Model with Covariates (Model B)**

Next, a model with the covariates, child sex and maternal education, included (Model B; Figure 4) was examined and the fit indices were suggestive of mediocre model fit, \( \chi^2(16) = 65.49, p < .001; \) RMSEA = 0.09 (90% CI = 0.07 – 0.12); CFI = 0.91. Child sex did not significantly predict children’s EF or vocabulary outcomes at any age. However, maternal education was significantly associated with children’s age 3 EF, age 3 vocabulary, and age 4 EF values (standardized coefficients ranged from .14 to .28; all p < .05). That is, children of mothers with a college degree scored higher on the PPVT at age 3 and on the composited 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 paths between age 2 EF and age 3 vocabulary, \( b = 0.10, SE = 0.06, p = 0.084 \), and between age 4 vocabulary and age 6 EF, \( b \)
= 0.16, SE = 0.09, p = 0.056, were no longer significant. A 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 the smaller model, Model A, better fit the data (Δχ² = 24.17, Δdf = 4, p = .05).

Post-hoc Panel Analyses (Model C)

Despite Model B’s relatively poor 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 significantly 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 5), which demonstrated acceptable and comparatively improved model fit, χ²(20) = 56.12, p < .001; RMSEA = 0.07 (90% CI = 0.05 – 0.09); CFI = .93. A second Chi-square difference test was conducted to compare model fit between Model A and Model C. The test indicated that the trimmed model, Model C, better fit the data (Δχ² = 14.80, Δdf = 8, p = .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 EF skill at ages 3, 4, and 6.

3.4 Mediation Models

Private Speech Model

Because the model is fully saturated, perfect model fit was achieved, χ² = 0, df = 0; RMSEA = 0; CFI = 1 (Figure 6, Model 1). Children with larger expressive vocabularies in toddlerhood (age 2) produced more mature private speech during the preschool years (age 4), b = 0.18, SE = 0.06, p = 0.004, and exhibited greater EF skills during the elementary school years.
(age 6), \( b = 0.16, \ SE = 0.07, \ p = 0.021 \). However, the direct effect from age 4 private speech to age 6 EF was not significant, \( b = 0.06, \ SE = 0.08, \ p = 0.458 \). No evidence of mediation was detected in the model as the indirect effect of age 2 vocabulary size on age 6 EF through age 4 private speech was not significant, \( b = 0.01, \ SE = 0.02, \ p = 0.498, \ 95\% \ CI [-0.015, 0.048] \).

**Visual Attention Model**

Once again, perfect model fit was achieved because the model estimated was fully saturated, \( \chi^2 = 0, \ df = 0; \ RMSEA = 0; \ CFI = 1 \) (Figure 6, Model 2). The results show that children who exhibited greater EF skills toddlerhood (age 2) had larger vocabularies during the elementary school years (age 6), \( b = 0.28 \ SE = 0.07, \ p < .001 \). Additionally, children who demonstrated greater visual attention skills as preschoolers (age 4) had larger vocabularies during the elementary school years (age 6), \( b = 0.18 \ SE = 0.09, \ p = .040 \). The direct effect of age 2 EF on age 4 visual attention was not significant, \( b = 0.01, \ SE = 0.07, \ p = .854 \), and no evidence of mediation was detected in the model as indicted by the non-significant indirect effect, \( b = 0.002, \ SE = 0.01, \ p = .868, \ 95\% \ CI [-0.023, 0.034] \).
Chapter 4

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 this inconsistency may be due in part to the diverse study designs and analytic strategies utilized by developmental researchers. Thus, the goal of my dissertation research was to implement a robust methodological and analytic approach to investigating the developmental link between childhood EF and vocabulary across early childhood (Aim #1). Additionally, this study sought to extend the existing literature by testing empirically-informed mechanisms (i.e., private speech and visual attention) that may account for the predictive link between children’s early and later EF/vocabulary (Aims #2 and #3).

4.1 The Longitudinal Factor Structure of EF

Confirmatory factor analysis (CFA) is a useful analytic tool that enables researchers to test theory-driven hypotheses regarding the composition of latent constructs, such as EF (Kline, 2011). CFA was therefore used in the current study to evaluate the latent structure of EF at various developmental timepoints across early childhood (i.e., at ages 2, 3, 4, and 6). Based on previous factor analyses in the developmental literature (Fuhs & Day, 2011; Wiebe et al., 2008; 2011), it was hypothesized that a unidimensional model of EF would fit the data at each age (Hypothesis 1A). However, this hypothesis was not supported at any age as weak, albeit
statistically significant, factor loadings were consistently detected even after making adjustments to the specified measurement models (Table 5). This finding suggests that a unitary factor structure of EF was not a good fit for the data in this study, which does not replicate the findings reported in the existing developmental literature.

Previous research illustrates that task selection may play an important role in determining the latent factor structure of early childhood EF. For example, Miller and colleagues (2012) were able to replicate the one-factor structure of EF found by Wiebe et al. (2008, 2011) when Miller et al. used similar EF tasks. However, when a different battery of EF tasks (that minimized the overlap in inhibitory control and working memory skill) was examined, Miller et al. (2012) report that a two-factor model best fit the data. To lessen concerns related to the task impurity problem (Fuhs & Day, 2011), my dissertation study purposely incorporated EF tasks that are thought to evaluate a diverse array of EF-related processes that vary considerably in their motor or language demands (see Garon et al.’s (2008) review for an in-depth description of developmentally-appropriate child EF tasks). At each age in my study, children’s scores on the EF tasks administered were either not correlated or weakly correlated with one another (Pearson correlation coefficients ranged from .03 to .24; Table 3). As such, the task selection criteria that I adopted may have resulted in less common variance being shared among EF tasks in comparison to other studies, which in turn could have influenced the weak factor loadings that were observed. In considering reports of publication bias in the psychological literature (Kühberger et al., 2014), it’s also important to note that studies failing to find evidence of a well-fitting, unitary factor structure of EF in early childhood may be underrepresented in the developmental literature. Taken together, further research is needed to better understand the source of error in
the factor analysis model, and to examine the effect of task selection specifically on the longitudinal factor structure of EF in early childhood.

### 4.2 The Predictive Link Between EF and Vocabulary Across Early Childhood

Next, my dissertation study sought to examine 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, I anticipated that early vocabulary would predict later EF (e.g., age 2 vocabulary → age 3 EF; Hypothesis 1B) and that early EF would predict later vocabulary (e.g., age 2 EF → age 3 vocabulary; Hypothesis 1C). Not surprisingly, children’s EF composite values were positively correlated with their expressive/receptive vocabulary scores both within and across measurement waves (Table 3). Between the three panel models generated, however, an interesting pattern of cross-lagged paths emerged.

First, hypothesis 1B 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 (Figure 5). This finding illustrates that across early childhood, the size of children’s vocabulary at one timepoint was consistently 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 and colleagues
(2014) also report that children’s PPVT scores at age 3 predicted their EF skills when measured at 4.5 years. My dissertation research therefore 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 1C 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 (Figure 3). This pathway was no longer significant, however, once maternal education was introduced in the model (Figures 4 and 5). 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 and colleagues (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 my trimmed panel model may not have been significant because multiple linguistically simple EF tasks were incorporated in my study.

Although not of primary interest in the current study, the autoregressive effects in my trimmed panel model indicate that there is stability in children’s vocabulary size and EF performance over time in 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 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 in my study were not significant because children exhibited such strong stability in their vocabulary scores across early childhood. Taken together, my 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 effortful cognitive tasks.
4.3 Examining the Indirect Effects of Private Speech and Visual Attention

What remains unclear from the pattern of correlations and the panel models discussed above is the mechanisms underlying the longitudinal relations between early childhood EF and vocabulary. In discussing the link between EF deficits and language impairment observed 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 the successful planning and execution of goal-directed behavior (the deep level). Likewise, while early word learning/speech production may require EF skills to focus on novel word-referent pairs or organize word meanings in the mind (the deep level), it’s also possible that behavioral assessments of vocabulary inadvertently tap into EF-related processes (e.g., inhibiting the urge to point to an interesting picture in favor of the one that was verbally requested on the PPVT; the superficial level). As such, my dissertation research also sought to examine whether two empirically-informed variables that operate at the deep level (i.e., private speech and visual attention) mediate the hypothesized association between age 2 and age 6 EF/vocabulary.

Private Speech

The second aim of my study was to evaluate whether vocabulary size in toddlerhood (age 2) predicts EF performance during the elementary school years (age 6) via children’s engagement in private speech during the preschool years (age 4). Based on the developmental literature, the following three hypotheses were generated: Age 4 private speech would be positively correlated with age 2 vocabulary and age 6 EF (Hypothesis 2A); Age 2 vocabulary would directly influence age 6 EF (Hypothesis 2B); Age 2 vocabulary would indirectly influence
age 6 EF through age 4 private speech (Hypothesis 2C). Partial evidence was found for hypothesis 2A as age 4 private speech was significantly correlated with age 2 expressive vocabulary \((r = .18, p = .004)\), but not with children’s EF performance at age 6 \((r = .07, p = .393)\). In this sense, children who were able to say more words as toddlers produced a greater proportion of mature private speech as preschoolers. Next, the private speech mediation model indicated that there was a significant direct effect of age 2 vocabulary on age 6 EF (Figure 6). In support of hypothesis 2B, this finding demonstrates that children’s early word production skills are predictive of their performance on a battery of EF tasks much later in childhood. However, preschool private speech did not mediate this longitudinal association as expected (Hypothesis 2C) given that the indirect effect was not statistically significant.

Despite the lack of evidence for a mediational effect, these findings demonstrate that early vocabulary acquisition has a significant, direct influence on children’s later cognitive development. It could be argued that word knowledge is fundamental to being able to direct meaningful speech toward the self as a tool to modulate one’s thoughts and actions. And yet, to my knowledge, no research has examined the predictive link between early vocabulary size and later private speech production in early childhood. This is surprising because if overt/covert self-talk plays an important role in cognitive and behavioral self-regulation as the literature would suggest (see Alderson-Day & Fernyhough (2015) for a review on inner speech across the lifespan), then identifying factors that facilitate the development of private speech is essential to early childhood researchers. Although Manfra and Winsler (2006) report that 3- to 5-year-olds with larger expressive vocabularies are more aware of their own use of private speech, these authors’ concurrent analyses can’t speak to whether vocabulary is related to the amount or maturity of children’s private speech. My dissertation research therefore adds to the
developmental literature by demonstrating that children’s expressive vocabulary size during the second postnatal year predicts the degree to which children produce mature and/or task-relevant private speech when completing a challenging task during the preschool years.

Although it has been proposed that private speech plays an important role in promoting self-regulatory skills in early childhood, very few studies examining the relation between private speech and EF have been longitudinal. Whedon et al. (2021) report that the maturity of three-year-olds’ private speech positively predicted their inhibitory control performance at age 4, and this association was moderated by children’s temperamental anger reactivity. However, age 4 private speech was unrelated to children’s age 6 EF score in my dissertation study. If it was simply the case that private speech plays a more predominant role in response inhibition as opposed EF more broadly, I would have expected age 4 private speech to be correlated with children’s scores on the Stroop task at age 6; however, this was not the case ($r = -.01, p = .874$).

Alternatively, preschool private speech 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., span or conflict tasks), others are more motivational in nature (e.g., delay-of-gratification tasks) and may therefore also require emotion regulation skills. Interestingly, preschoolers’ private speech during the challenging puzzle task was only significantly correlated with their concurrent performance on the Gift Peek task in this study. Because all three EF tasks administered at age 6 are arguably emotionally neutral, additional research is needed to support this interpretation. Finally, it is also possible that the extent to which private speech has been internalized by age 4 is a better predictor of EF at age 6 than the proportion of mature, auditory private speech. Indeed, Winsler et al. (2003) report that children produce substantially less overt private speech during problem-solving tasks as measured across
the preschool years when children were 3.5, 4, and 4.5 years of age. Because the internalization of private speech is thought to be a gradual process (Vygotsky, 1978), it may be useful to examine changes across early childhood in children’s private speech production in future research.

**Visual Attention**

The third and final aim of my dissertation study was to examine whether EF in toddlerhood (age 2) predicts vocabulary outcomes during the elementary school years (age 6) via children’s visual attention abilities as preschoolers (age 4). Based on previous research, the following three hypotheses were generated: Age 4 visual attention would be positively correlated with both age 2 EF and age 6 vocabulary (Hypothesis 3A); Age 2 EF would exert a direct effect on age 6 vocabulary (Hypothesis 3B); Age 2 EF would indirectly predict age 6 vocabulary through age 4 visual attention (Hypothesis 3C). Similar to the findings above, partial evidence was found for hypothesis 3A as age 4 visual attention was positively correlated with age 6 vocabulary ($r = .17, p = .023$), but not with age 2 EF ($r = .01, p = .861$). Thus, children who exhibited greater attention skills as preschoolers during a visual search task had larger receptive vocabularies when measured at age 6. Additionally, the mediation model indicated that although there was a significant direct effect of age 2 EF on age 6 vocabulary (Hypothesis 3B), no evidence of indirect effect through age 4 visual attention was detected (Hypothesis 3C; Figure 6).

The predictive link between attention and vocabulary development is well-established among infancy researchers. That is, children’s early orienting and sustained attention skills have been found to predict their later expressive/receptive vocabulary acquisition (Colombo et al., 2004; Kannass & Oakes, 2008; Yu et al., 2019). The current study therefore extends these findings by replicating this positive, longitudinal association between visual attention and
receptive vocabulary size much later in early childhood. By comparison, the directionality of the association between visual attention and EF is less understood, perhaps in part because many EF tasks seem to require some attention skills (Best & Miller, 2010). For example, while Blankenship et al. (2019) and Kraybill et al. (2019) illustrate that infant attention directly predicts later EF performance, Jaekel et al. (2016) report that children’s EF abilities in toddlerhood are predictive of their later attentional skills in middle childhood. Although age 4 visual attention was not related to EF at age 2 in the current study, it was significantly correlated with children’s EF performance at age 4 and age 6. Thus, contrary to my initial hypothesis, visual attention skills in preschool may play a role in promoting the continued development of both children’s vocabulary and EF abilities later in childhood.

Additionally, other aspects of children’s early attentional functioning not measured in the present study may better account for the association between early EF and later vocabulary size. Indeed, attention is an intricate and multifaceted construct that captures one’s ability to flexibility shift, maintain, terminate, and reengage attention across a variety of contexts (Erickson et al., 2015; Ruff & Capozzoli, 2003). Although the attention task that was administered in this study is a well-established task that requires children to search for target objects among distraction elements, future research should incorporate various attention tasks (e.g., spatial cueing paradigms; Baek et al., 2021; Posner, 1980) and/or multiple markers of attention (e.g., latency to locate the target objects) better clarify the mechanisms involved in the longitudinal relation between EF and vocabulary development.

4.4 Limitations

Taken together, these analyses illustrate an interesting developmental pattern of associations between EF, vocabulary, private speech, and visual attention 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, I was unable to measure only receptive or expressive vocabulary using the same instrument at each data collection wave. Nonetheless, 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. 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 up through age 6.

Relatedly, one of the benefits of factor analysis is that it examines the relations between a set of manifest variables and their presumed underlying construct, where measurement errors are additional parameters that are estimated for each indicator (Kline, 2011). In contrast, composite scores are formed by aggregating indicators and therefore do not fully incorporate measurement error, which may yield biased estimates (Bogicevic & Busjisc, 2021). Thus, an additional limitation of the present study is its use of composite EF values. Future research should therefore consider examining an empirically representative, single indicator of EF with stronger psychometric properties as an alternative analytic strategy.

Third, aspects of children’s language development that extend beyond expressive/receptive vocabulary (e.g., grammar, pragmatic skills, or communicative gesturing) were not assessed in the present study, and the measures used to assess early childhood
vocabulary may not have captured the full breadth of children’s word knowledge/production. 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). Future research should therefore explore the bidirectional links between EF and language more broadly, especially when considering that improvements in some verbal skills (e.g., children’s use of decontextualized speech; Uccelli et al., 2019) typically emerge later in early childhood.

Next, 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 emerging. 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, further research is warranted 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 Caucasian 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 stringent analytic approach that was implemented and the large sample size collected across an extensive developmental age range.
Chapter 5

5 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 potentially 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/vocabulary abilities predict children’s later outcomes respectively. The first objective of my dissertation study was therefore 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. The current study also sought to evaluate mechanisms based on the developmental literature that could account for the predictive link between age 2 and age 6 EF/vocabulary. Although no evidence of mediation was detected, the novel results demonstrate an interesting pattern of developmental associations between EF, vocabulary, private speech, and visual attention. Coupled with previous longitudinal research on this topic, my dissertation findings indicate that children’s early vocabulary abilities in play an important role in predicting children’s later self-modulated and goal-directed actions at various timepoints across early childhood.
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Table 1

Sample Demographics at Each Data Collection Wave

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

*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 both 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) was received (n = 20).
### Table 2

*Descriptive Statistics for Primary Study Variables*

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<th></th>
<th>N</th>
<th>Min</th>
<th>Max</th>
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<th>Std. Dev.</th>
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<tr>
<td>Age 2 MCDI</td>
<td>333</td>
<td>5</td>
<td>683</td>
<td>303.23</td>
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<td>Age 3 PPVT</td>
<td>281</td>
<td>9</td>
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<td>264</td>
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<td>194</td>
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<td>.43</td>
<td>.41</td>
<td>.30</td>
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*Note. Descriptive statistics were generated after Winsorization. MCDI = MacArthur-Bates Communicative Development Inventory: Words and Sentences; PPVT = Peabody Picture Vocabulary Test; DCCS = Dimensional Change Card Sort task; FDS = Forward Digit Span; BDS = Backward Digit Span; Stroop (seconds) = Number Stroop (reaction time in seconds).*
### Table 3

**Pearson Correlation Matrix for Primary Study Variables**

| Age 2 Tasks | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|-------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1. MCDI     | -- |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 2. DCCS     | .10 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 3. TT       | .26** | .17** |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 4. Crayon   | .18** | .19** | .20** |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 5. EF_2     | .24** | .68** | .68** | .71** |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Age 3 Tasks |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 6. PPVT     | .32** | .13* | .08 | .18** | .19** |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 7. DCCS     | .27** | .09 | .06 | .23** | .20** | .26** |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 8. FDS      | .26** | .08 | .07 | .13 | .15 | .38** | .16 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 9. Day/Night| .15* | .11 | .19** | .18** | .20** | .06 | .22** | .03 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 10. EF_3    | .31** | .10 | .12 | .23** | .21** | .27** | .78** | .65** | .72** |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Age 4 Tasks |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 11. PPVT    | .31** | .07 | .01 | .08 | .07 | .77** | .17* | .28** | .12 | .20** |    |    |    |    |    |    |    |    |    |    |    |    |
| 12. DCCS    | .38** | .20** | .16* | .18** | .27** | .36** | .22** | .30** | .05 | .19** | .26** |    |    |    |    |    |    |    |    |    |    |    |
| 13. FDS     | .26** | .02 | .06 | .10 | .06 | .24** | .09 | .35** | .19* | .25** | .24** | .22** |    |    |    |    |    |    |    |    |    |    |
| 14. Gift Peek| .16* | .03 | .15* | .11 | .15* | .15* | .03 | .17 | .23** | .15* | .09 | .24** | .20** |    |    |    |    |    |    |    |    |    |
| 15. Attention| .16* | .03 | .09 | .01 | .01 | .15* | .03 | .10 | .07 | .08 | .19** | .12 | .19** | .13 |    |    |    |    |    |    |    |    |
| 16. PS      | .18** | .11 | .01 | .04 | .03 | .10 | .03 | .06 | .08 | .01 | .13* | .05 | .10 | .18** | .06 |    |    |    |    |    |    |    |
| 17. EF_4    | .38** | .13* | .16* | .19** | .23** | .35** | .16* | .40** | .23** | .27** | .27** | .72** | .70** | .71** | .22** | .15* |    |    |    |    |    |
| Age 6 Tasks |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 18. PPVT    | .41** | .19* | .14 | .27** | .28** | .61** | .17* | .29** | .19* | .27** | .66** | .38** | .17* | .25** | .17* | .13* | .39** |    |    |    |    |
| 19. DCCS    | .15* | .22** | .21* | .12 | .26** | .28** | .11 | .27** | .02 | .09 | .26** | .21** | .19* | .05 | .10 | .06 | .21** | .34** |    |    |    |    |
| 20. BDS     | .15* | .15 | .07 | .13 | .11 | .29** | .04 | .21* | .00 | .09 | .21** | .21** | .24** | .09 | .10 | .10 | .24** | .33** | .19** |    |    |    |
| 21. Stroop  | .04 | .25** | .02 | .05 | .08 | .01 | .19* | .04 | .01 | .09 | .02 | .16* | .17* | .05 | .05 | .01 | .12 | .16* | .17* | .21** |    |
| 22. EF_6    | .16* | .29** | .05 | .10 | .21** | .29** | .06 | .21* | .01 | .07 | .21** | .29** | .28** | .07 | .15* | .07 | .30** | .42** | .67* | .71** | .69** |    |

*Note.* *p < 0.05; **p < 0.01; Pearson correlation matrix was generated after Winsorization. MCDI = MacArthur-Bates Communicative Development Inventory: Words and Sentences; TT = Tongue Task; Crayon = Crayon Delay; EF_(#) = EF composite score at a given timepoint; PPVT = Peabody Picture Vocabulary Test; DCCS = Dimensional Change Card Sort task; FDS = Forward Digit Span; BDS = Backward Digit Span; PS = Private Speech; Stroop = Reverse scored Number Stroop (reaction time).
### Table 4

*Bivariate Correlations Between the Primary Variables and Covariates*

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</tr>
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<td>2. DCCS</td>
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<td>.19**</td>
</tr>
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<td>3. TT</td>
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<td>8. FDS</td>
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<td>9. Day/Night</td>
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*Note.* *p* < 0.05; **p** < 0.01; Bivariate correlations were calculated after Winsorization. Child sex was coded as 0 = boy and 1 = girl, and maternal education was coded as 0 = no college education and 1 = college education. MCDI = MacArthur-Bates Communicative Development Inventory: Words and Sentences; TT = Tongue Task; Crayon = Crayon Delay; EF_(#) = EF composite score at a given timepoint; PPVT = Peabody Picture Vocabulary Test; DCCS = Dimensional Change Card Sort task; FDS = Forward Digit Span; BDS = Backward Digit Span; PS = Private Speech; Stroop = Reverse scored Number Stroop (reaction time).
Table 5

Standardized Estimates of the Factor Loadings on EF Across Timepoints for the Initial and Best-Loading Measurement Models

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Note. † indicates EF tasks that were dropped from the correlation matrix and longitudinal analyses. All factor loadings are significant at p < .05. Crayon = Crayon Delay; DCCS = Dimensional Change Card Sort task; FDS = Forward Digit Span; BDS = Backward Digit Span; Stroop (prop) = Number Stroop (proportion); Stroop (RT) = Reverse scored Number Stroop (reaction time).
Figure 1

*Conceptual Autoregressive, Cross-Lagged Model Diagram: Vocabulary and EF from ages 2 to 6*

Note. TT = Tongue Task; Crayon = Crayon Delay; DCCS = Dimensional Change Card Sort task; FDS = Forward Digit Span; BDS = Backward Digit Span; Stroop = Number Stroop; MCDI = MacArthur-Bates Communicative Development Inventory: Words and Sentences; PPVT = Peabody Picture Vocabulary Test.
Figure 2

*Conceptual Mediation Model Diagrams: Child Vocabulary, EF, Private Speech, Visual Attention*

**Model 1**

![Diagram](image)

**Model 2**

![Diagram](image)

*Note. PS = Private speech.*
Figure 3

Autoregressive Cross-Lagged Panel Model (Model A)

Note. † $p < .10$; * $p < 0.05$; ** $p < 0.01$; *** $p < .001$. Standardized estimates are presented.

Solid black lines represent statistically significant paths; Solid gray lines represent non-significant paths.
Figure 4

Autoregressive Cross-Lagged Panel Model with Covariates (Model B)

Note. † p < .10; * p < 0.05; ** p < 0.01; *** p < .001. Standardized estimates are presented.

Solid black lines represent statistically significant paths; Solid gray lines represent non-significant paths.
Figure 5

Trimmed Autoregressive Cross-Lagged Panel Model (Model C)

Note. † p < .10; * p < 0.05; ** p < 0.01; *** p < .001. Standardized estimates are presented.

Solid black lines represent statistically significant paths; Solid gray lines represent non-significant paths.
Figure 6

Preschool Private Speech and Visual Attention Mediation Models

Model 1

![Diagram of Model 1]

Model 2

![Diagram of Model 2]

Note. †p < .10; *p < 0.05; **p < 0.01; ***p < .001. Standardized estimates are presented.

Solid black lines represent statistically significant paths; Solid gray lines represent non-significant paths. PS = Private speech.
Appendices

Appendix A: Descriptions of the Excluded EF Tasks

A-not-B with invisible displacement (Age 2). This task is a looking version of the infant A-not-B task that has been adaptive to assess executive functioning in toddlerhood (Bell, 2001, 2002; Diamond et al., 1997). Toddlers watched as an attractive object was hidden under a cup that a research assistant then shifted across a tabletop to one side (location A; counterbalanced left/right). A board was then placed between the child and the cup for 5-seconds to obscure the child’s vision of it. During this time, the research assistant distracted the toddler and discreetly placed a second, empty cup parallel but distant from first cup on the opposite side of the table (location B). The board was then removed, and the toddler was instructed to locate the hidden object. Toddlers’ first look toward either location was coded and after achieving two consecutively correct same-side searches, the hiding location was reversed (pattern AAB). The variable of interest was the proportion of correct responses across both the reversal and non-reversal trials.

Crayon Delay (Age 3). The Crayon Delay task 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 markers (at age 3) 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 to not touch the markers, the box, or the paper until the research assistant returned. The child was left alone with the coloring supplies for 120-seconds. The variable of interest was the latency (in seconds) to touch any of the coloring materials.
Yes/No task (Age 4). Theoretically and procedurally similar to Gerstadt et al.’s (1994) Day/Night task, the Yes/No task required children to say ‘‘yes’’ when the research assistant shook their head horizontally to indicate no, and to say ‘‘no’’ when the research assistant vertically nodded their head to indicate yes (Wolfe & Bell, 2004; 2007). Children were given two practice trials, which were followed by 16 test trials (eight “yes” trials and eight “no” trials; counterbalanced yes/no). The variable of interest was the proportion of correct responses.

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 were required to count the number of digits (e.g., “777” = 3). Children recorded their responses on a keyboard and completed 25 test trials in total. The variable of interest was the proportion of correct responses.
Appendix B: Descriptive Statistics for the Originally Proposed Study Variables

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*Note.* Rows with excluded EF tasks are bolded; Descriptive statistics were generated after Winsorization. MCDI = MacArthur-Bates Communicative Development Inventory: Words and Sentences; PPVT = Peabody Picture Vocabulary Test; DCCS = Dimensional Change Card Sort task; FDS = Forward Digit Span; BDS = Backward Digit Span; Stroop prop = Number Stroop (proportion).
### Appendix C: Correlation Matrix for the Originally Proposed Study Variables

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*Note.* Rows/columns with excluded EF tasks are bolded. Pearson correlation matrix was generated after Winsorization. MCDI = MacArthur-Bates Communicative Development Inventory: Words and Sentences; TT = Tongue Task; Crayon = Crayon Delay; PPVT = Peabody Picture Vocabulary Test; DCCS = Dimensional Change Card Sort task; FDS = Forward Digit Span; BDS = Backward Digit Span; PS = Private Speech; Stroop = Number Stroop (proportion).
Appendix D: IRB Approval Letter (#05-243)

Division of Scholarly Integrity and Research Compliance
Institutional Review Board
North End Center, Suite 4120 (MC 0467)
330 Turner Street NW
Blacksburg, Virginia 24061
540.231.3732
irs@vt.edu
http://www.research.vt.edu/irb homepage

MEMORANDUM

DATE: April 11, 2022


FROM: Virginia Tech Institutional Review Board (FWA00000572)

PROTOCOL TITLE: Psychobiology of Cognitive Development

IRB NUMBER: 05-243

Effective November 12, 2021, the Virginia Tech Institution Review Board (IRB) approved the Continuino Review request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except when necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:
https://secure.research.vt.edu/external/irb/responsibilities.htm

(Please review responsibilities before beginning your research)

PROTOCOL INFORMATION:

Approved As: Expedited, under 45 CFR 46.110 category(ies) B(c)
Protocol Approval Date: December 12, 2021
Protocol Expiration Date: December 11, 2022
Continuing Review Due Date*: October 24, 2022

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

ASSOCIATED FUNDING:

The table on the following page indicates whether grant proposals are related to this protocol, and which of the listed proposals, if any, have been compared to this protocol, if required.
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* Date this proposal number was compared, assessed as not requiring comparison, or comparison information was revised.

If this protocol is to cover any other grant proposals, please contact the HRPP office (irb@vt.edu) immediately.
Appendix E: IRB Approval Letter (#12-947)

MEMORANDUM

DATE: September 13, 2021


FROM: Virginia Tech Institutional Review Board (FWA00000572)

PROTOCOL TITLE: Psychobiology of Cognitive Development in Middle Childhood

IRB NUMBER: 12-947

Effective September 13, 2021, the Virginia Tech Institution Review Board (IRB) approved the Continuing Review request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at: https://secure.research.vt.edu/external/irb/responsibilities.htm

(Please review responsibilities before beginning your research.)

PROTOCOL INFORMATION:

Approved As: Expedited, under 45 CFR 46.110 category(ies) 8(c)
Protocol Approval Date: October 10, 2021
Protocol Expiration Date: October 9, 2022
Continuing Review Due Date*: September 18, 2022

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

ASSOCIATED FUNDING:

The table on the following page indicates whether grant proposals are related to this protocol, and which of the listed proposals, if any, have been compared to this protocol, if required.
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*Date this proposal number was compared, assessed as not requiring comparison, or comparison information was revised.

If this protocol is to cover any other grant proposals, please contact the HRPP office (irb@vt.edu) immediately.