A LATENT FACTOR ANALYSIS OF PRESCHOOL EXECUTIVE FUNCTIONS: INVESTIGATIONS OF ANTECEDENTS AND OUTCOMES

Jessica Hershberger Kraybill

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Martha Ann Bell, Chair
Kirby Deater-Deckard
Jungmeen Kim-Spoon
Cynthia Smith

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(ABSTRACT)

The current study investigated the nature of executive function (EF) abilities in preschoolers using confirmatory factor analysis; potential antecedents and outcomes were examined as well. Executive function refers to higher order cognitive abilities necessary to consciously and deliberately persist in a task; these abilities are associated with a wide variety of important developmental outcomes. Within the developmental literature, studies on EF development in early childhood have focused most often on the constructs of working memory (WM) and inhibitory control (IC). Whether WM and IC are dissociable cognitive abilities is an unresolved issue within the literature; accordingly, performance on a battery of EF tasks at ages 2 and 4 was assessed to determine if EF structure at these ages is best described by a single factor or two factors consisting of working memory and inhibitory control. At both ages, a unitary model fit the data well. Longitudinal relations between attention in infancy, preschool EF, and school readiness and social competency at age 4 were also examined. Although infant attention measures failed to significantly predict later EF, pathways between age 4 EF (but not age 2 EF) and all age 4 outcomes were significant and in the expected direction. Understanding the nature of EF and the factors associated with optimal regulatory abilities is necessary for both theoretical and practical purposes, and given the considerable improvements that happen to EF abilities during this time period in early childhood, longitudinal studies such as this one are necessary to address issues of developmental change.

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Chapter 1
Introduction

Executive function (EF) refers to higher order cognitive abilities necessary to consciously persist in a task or behavior despite facing challenges in the form of competing rules, distractions, or delays (Espy, Sheffield, Wiebe, Clark, & Moehr, 2011). Execution of EF relies heavily on the prefrontal cortex (PFC) and significant maturational advances in PFC development coincide with significant gains in EF abilities (see Diamond, 2013, for review). Brain-based improvements in EF abilities from the toddler to kindergarten years support the transition from external (i.e., parent-based) to more internal means of regulating behavior. With regulatory-related skills to resist inappropriate behaviors and instead respond more suitably to situational demands, to maintain attentional focus amid distraction, and to shift attention and perspective when required, EF allows children increasing control over their own actions.

Within the developmental literature, studies on EF development in early childhood have focused most often on working memory (WM) and inhibitory control (IC). (A third variable, set shifting, has often been discussed in the adult literature but is not part of the current study because it is often difficult to measure in early childhood; see Garon, Bryson, & Smith, 2008, for a review.) Working memory refers the ability to maintain information in one's mind while manipulating that information in some way whereas IC refers to the ability to resist inappropriate behaviors and instead respond appropriately (e.g., Diamond, 2006). Kirkham, Cruess, and Diamond (2003) argue that both WM and IC play a central role in overcoming "attentional inertia," a key challenge to successful EF deployment characterized by the inability to disengage from a frame of mind that is no longer relevant to the current situation.

Whether WM and IC are dissociable cognitive abilities is an unresolved issue within the literature; there is a general lack of consensus about the underlying structure of EF and the extent to which it represents a unitary construct or one comprised of related yet separable cognitive abilities. Factor analysis has been proposed as one way to investigate this issue, as it allows for the testing of complex relationships between sets of observed and latent variables. Accordingly, the first goal of the current study was to examine the nature of EF in preschoolers using confirmatory factor analysis.

A significant body of work has documented the relation between EF deficits and early child development. Low levels of EF are associated with clinical-level ADHD symptamotology (e.g., Berlin, Bohlin, & Rydell, 2003; Campbell & von Stauffenberg, 2009; Gewirtz, Stanton-Chapman & Reeve, 2009), social difficulties (Fahie & Symons, 2003), academic difficulties (Liew, McTigue, Barrois, & Hughes, 2008; Zhou, Main, & Wang, 2010), and difficulty regulating emotions (Lemery, Essex, & Snider, 2002; Kochanska, Murray, & Harlan, 2000). One study indicates that EF deficits may *precede* problem behaviors (Riggs, Blair, & Greenberg, 2003), making a thorough understanding of the nature of executive functioning in early childhood especially crucial.

The bulk of EF research is cross-sectional in nature and several researchers have recently put out a call for longitudinal research examining the development of EF during early childhood (e.g., Garon, Bryson, & Smith, 2008). As longitudinal research is essential for achieving a coherent theory of developmental changes in EF, another goal of the current study was to investigate longitudinal relations between EF and two important child outcomes, school readiness and social competency.

Rudimentary EF abilities emerge late in the first year of life; infants between the ages of 8-12 months can inhibit the impulse to reach to a previously rewarding but incorrect location on the A-not-B task (Bell, 2012; Bell & Fox, 1992; Diamond, 1985, 1990; Diamond, Prevor, Callender, & Druin, 1997; Cuevas, Swingler, Bell, Marcovitch, & Calkins, 2012). Abilities continue to progress in early childhood but improve most dramatically between the ages of 3 and 5 (e.g., Carlson, 2005; Jacques & Zelazo, 2001), with particular gains seen in tasks requiring inhibitory control (Diamond, 2006). Data on the Stroop-like day-night task illustrate this dramatic improvement. Slightly less than half of 3-year-olds and slightly more than half of 4-year-olds can successfully complete this task, in contrast to 80% of 5-year-olds (Carlson, 2005; Gerstadt, Hong, & Diamond, 1994). Continuous but more gradual advances in EF ability occur in middle childhood (Romine & Reynolds, 2005); these gains are supported by changes in frontal lobe development (Rueda et al., 2004). Most children start to demonstrate adult-like levels of performance on EF tasks around 7 years of age (Diamond & Taylor, 1996).

Individual differences in EF during early childhood have been linked with biologically-based variables such as age (e.g., Carlson, 2005), gender (e.g., O'Brien, Dowell, Mostofsky, Denckla, & Mahone, 2010), effortful control (Blair & Razza, 2007), and brain electrical activity (e.g., Wolfe & Bell, 2004, 2007). Despite evidence that EF abilities are highly heritable (Friedman, Miyake, Young, DeFried, Corley & Hewitt, 2008), they nonetheless show signs of malleability, as comprehensive EF training substantially improves performance on novel tasks (Diamond et al., 2007). The protracted development of the PFC, which continues well into adulthood (Luna et al., 2001), implies that this brain region may be susceptible to environmental influences. Indeed, recent studies provide support for the idea that environmental factors influence EF abilities, as responsive parenting has been linked with higher preschool EF abilities (e.g., Bernier, Carlson, & Whipple, 2010).

Attention is commonly believed to support and enable successful EF deployment (Norman & Shallice, 1986), and findings in early EF development support the concurrent relationship between attentional abilities and preschool EF (Espy & Bull, 2005). Far less is known, however, about the impact of infant attention on subsequent EF; one of the goals of the current study was to examine this relationship.

The Nature of Executive Functions in Early Childhood

Although definitions of EF often center around higher level cognitive regulatory processes that support goal-directed behavior (e.g., Espy, Sheffield, Wiebe, Clark, & Moehr, 2011), the construct itself lacks a universally accepted definition and numerous interpretations of EF exist within the literature. The lack of consensus regarding its precise nature understandably poses a challenge to the measurement of EF (e.g., Carlson, Zelazo, & Faja, 2013; Diamond, 2013). A particularly troublesome issue has been referred to as the task impurity problem (e.g., Miyake et al., 2000). EFs rely on a number of non-executive processes such as motor coordination. Because variance on EF tasks also reflects the effects of these non-executive processes, task performance cannot be seen as an absolute measure of EF. Executive function tasks, in other words, do not solely measure executive functioning.

Theories about the structure of EF fall largely into two camps. Researchers who advance a unitary view of EF speculate that a single ability (often related to attention) underlies and supports EF development; Zelazo and colleagues' Cognitive Complexity and Control-revised theory, for example, focuses on the integration of higher order rule structures (Zelazo, Muller, Frye, & Marcovitch, 2003). Other researchers, however, assert that EF is best viewed as an umbrella term comprised of fractionated, yet related, cognitive abilities. Different EF tasks often have relatively low correlations (e.g., Miyake et al., 2000), providing support for this hypothesis, although the low correlations often found may reflect other issues such as non-executive task demands.

Confirmatory factor analysis (CFA), a type of structural equation modeling, is an increasingly popular empirical approach to examining the structure and organization of EF. The ability of basic statistical methods to address sophisticated phenomena is limited, and given the dynamic and complex nature of development, particularly concerning inter- and intra-individual differences, structural equation modeling is a logical approach. As its name suggests, CFA is a theory-driven technique that allows *a priori* hypothesis testing of complex relationships between sets of observed and latent variables. Observed variables refer to those variables that the researcher can measure, such as performance on a particular task; their common variance is extracted to form latent variables. Latent variables are thus considered to be a more accurate and true measure of that particular construct (Bollen, 1989). Theoretical models in which the researcher specifies the relationships between observed and latent variables are tested to determine the extent to which they are confirmed by the data. Models that capture the relationships between latent and observed variables with the least number of paths are preferred for the sake of parsimony (Bollen, 1989).

Confirmatory factor analysis is a satisfactory means of examining EF for several reasons. Unlike statistical analyses that focus solely on observed variables, CFA addresses the issue of measurement error. Measurement error can have many different sources – tasks may not fully capture the underlying attribute, participants may be uncooperative, etc. – and can substantially bias empirical conclusions (Fuller, 1987). CFA explicitly models error terms so that observed variables are depicted as being the result of both the true score and measurement error. By extracting the *shared* variance among observed variables to form latent variables, CFA also addresses the task impurity problem. The results of studies that rely on individual EF tasks can be difficult to interpret, because performance likely reflects the effects of non-executive demands in addition to executive demands. A latent variable approach, however, allows the common variance among tasks with different non-executive requirements to be extracted and hence provides a more accurate reflection of genuine EF performance.

At least five CFA studies have found that a single factor model best explained performance on a battery of EF tasks among children between the ages of 3 and 6 (Fuhs & Day, 2010; Wiebe, Espy, & Charak, 2008; Hughes, Ensor, Wilson, & Graham, 2010; Wiebe et al, 2011, Miller et al., 2012). Weibe and colleagues (2008), for example, assessed the relative fit of a one factor model versus a two factor model comprised of WM and IC and reported that the unitary model was preferred. Although set shifting has been reported in the adult literature as a separate but related component of EF (Miyake et al., 2000), Fuhs and Day (2010) found that in a preschool sample, a two factor model consisting of IC and set shifting did not result in a significantly better fit than the one factor model. Despite existing concerns about potential effects of non-executive task demands on EF performance, Wiebe and colleagues (2008) report that tests of measurement invariance indicated that a unitary model was the best fit regardless of non-executive task demands. Likewise, prior research has found that socioeconomic status (SES) and gender are significantly related to EF abilities, but both Wiebe and colleagues (2008) and Willoughby and colleagues (2011) report invariance regarding gender and SES on performance.

These studies support the unitary nature of EF during early childhood and indicate that executive functioning abilities between the ages of 3 and 6 show strong signs of continuity. It should be noted, however, that Hughes and colleagues (2010) only included three tasks in their assessment of preschool EF, making a comparison of fractionated models impossible. Kline

(1998) recommends a minimum of three observed variables per latent factor, and so the unitary fit reported by Hughes and colleagues may simply be a result of the study's methodology and does not necessarily preclude the existence of a two factor structure.

Although empirical evidence supports the unitary nature of EF in preschool, limited research suggests that WM and IC abilities become increasingly individualized over the course of adolescence. Shing and colleagues (2010) report that a single factor model was the best fit from ages 4 to 9.5 years of age, but that between ages 9.5 and 14, a two factor model consisting of working memory and inhibitory control as was the best fit. Several researchers (e.g., Diamond, 2002) have proposed that WM and IC have different developmental trajectories, and indeed, Shing and colleagues (2010) reported that although factor loadings for WM abilities were unaffected by age, IC factor loadings in contrast were affected by age. The researchers suggest that differentiation of executive functions across late childhood and adolescence may be due to the protracted trajectory of inhibitory control. As the bulk of research has examined executive abilities in either early childhood or adulthood, further investigations of EF across late childhood and adolescence are warranted, particularly in light of the differentiation in WM and IC abilities that may be occurring during this time.

Miyake and colleagues (2000) report that adult EF is best viewed as three separate but correlated constructs; task performance among adult participants was best explained by a three factor model consisting of inhibitory control, working memory, and set shifting factors. A recent integrated framework for viewing the nature and organization of EFs suggests that EF in adulthood can best be understood as *both* a unitary and fractionated construct. Friedman and colleagues (Friedman et al., 2008, 2011, 2012) posit that individual EF abilities can be regressed onto their common abilities, yet still maintain unique abilities. Their research indicates that working memory, inhibitory control, and set shifting all load on a latent 'common EF' factor that represents the *unitary* nature of EF. Inhibitory control overlaps completely with common EF and thus has no IC-specific variance. After accounting for common EF, however, WM tasks load on a nested latent Working Memory Specific variable, and tasks measuring set shifting likewise load on a latent Set Shifting Specific variable, representing the *diversity* found in EF.

Taken as a whole, results from these studies provide support for the differentiation hypothesis (e.g., Garrett, 1946), which posits that cognitive abilities move from being relatively global and general in childhood to more differentiated and specialized in adulthood. The bulk of research examining age-related improvements in EF development in early childhood, however, has been cross-sectional in nature (e.g., Carlson & Moses, 2001, Diamond & Taylor, 1996; Espy, Bull, Martin, & Stroup, 2006). Indeed, the only study to examine EF structure in late childhood and adolescence used a cross-sectional design (Shing et al., 2010). Developmental change is a within-person phenomenon and accordingly is best studied with longitudinal research (Molenaar, Huizenga, & Nesselroade, 2003). Cross-sectional research offers a picture of normative development for typically developing children, but it only addresses developmental change at the group level, thus limiting conclusions that can be drawn regarding developmental changes. There is a clear need for longitudinal research documenting within-subject growth of EF during the preschool period (Garon, Bryson, & Smith, 2008).

The period of time from age 2 to age 3 is an understudied area in the executive function literature. Key improvements occur during this time in a variety of factors associated with EF abilities. Significant changes, for example, occur between the ages of 2 and 3 in terms of brain development (eg., Diamond, 2002), language acquisition, and attention (Garon, Bryson, & Smith, 2008), indicating that the transitional time from infancy to early childhood is a key period in development. No studies to date have used a latent analysis framework to examine EF abilities at age 2. The current study therefore used a longitudinal, latent variable approach to studying developmental changes in EF abilities at ages 2 and 4.

Infant Attention and Subsequent Child EF

Given the myriad of outcomes associated with executive functioning in childhood and beyond, understanding the factors that influence the development of executive functioning is important for theoretical as well as practical purposes. The ability to focus and sustain attention, particularly in the face of distraction, is a vital component of goal-directed behavior, and indeed one factor believed to support and enable successful EF deployment is attention (Norman & Shallice, 1986).

Posner and Rothbart (2013) propose that attention is an 'organ system,' or a brain-based ability reliant on separate but related brain networks involved in alerting, orienting, and executive attention. The alerting and orienting networks develop early in the first year of life and govern more reactive processes such as reaction to novelty and duration of orienting. Alerting involves an infant's degree of wakefulness and is the first and most basic form of attention that newborns manifest. In the first six months of life, infant attention is largely governed by external factors in the environment, such as novel stimuli, and initially involves the orienting network, which allows children to orient to environmental stimuli. Behavioral and neurological data support the role of alerting and orienting as the infant's primary means of attentional control by 7 months of age (Posner & Rothbart, 2013), and infant orienting behavior has been linked with later cognitive functioning measures. Look duration during infancy is commonly used as an index of attention, for example, and infants who were classified as short lookers (i.e., more sophisticated information processors), scored higher on subsequent IQ measures at 4.5 years of age (Rose, Slater, & Perry, 1986).

In contrast to the alerting and orienting networks, the executive attention network governs voluntary attention and supports emerging regulatory skills and thus is a more advanced form of attention that develops later in early childhood (see Posner & Rothbart, 1998, for a review). Starting at around 6 months of age, and over the course of early childhood (Rothbart & Posner, 2001), attention becomes more internally-directed and infants are increasingly able to engage in focused, voluntary attention, which helps enhance information processing (Richards, 2004). Resolving mental conflicts while processing information, as well as shifting one's attention to meet task demands, are central components of EF and are supported by this system (Rothbart & Posner, 2001). Executive attention allows children to selectively attend to environmental and internal stimuli that are compatible with their goals and tasks, while ignoring incompatible stimuli; young infants struggle with this.

Research supports the relationship between attentional abilities and preschool EF. Preschoolers who are able to selectively attend to an alternative object are able to successfully inhibit the impulse to reach for a desired stimulus (Mischel, Cantor, & Feldman, 1996; Peake, Hebl, & Mischel, 2002) and higher attention focusing in preschool is linked with higher inhibitory abilities (Jones, Rothbart, & Posner, 2003). Preschoolers' attentional control skills additionally predict their concurrent working memory performance (Espy & Bull, 2005).

Although attentional abilities during the preschool period are concurrently linked with EF, little is known about the relation between *infant* attention and preschool EF. Two recent studies indicate that look duration is related to regulatory skills in infants (Diaz & Bell, 2010; Morasch & Bell, 2012), suggesting that the relationship between rudimentary forms of attentional control and the ability to regulate one's behavior is present early in life. Only one study has examined infant information processing and later EF abilities. Rose, Feldman, and Jankowski (2012) assessed infant and toddler performance on tasks measuring memory, processing speed, and attention at 7 months, 12 months, 24 months, and 36 months of age. Participants were then administered a series of EF tasks assessing WM, IC, and set shifting abilities at age 11. Infant and toddler information processing abilities explained 9-19% of the variance in 11 year EF abilities, indicating that information processing abilities in infancy may have far-reaching effects on EF abilities in middle childhood. The effect that information processing abilities might have on EF earlier in development is still unknown, however. Given the rapid development of brain-based attentional and EF networks during infancy and early childhood, infant attention may be even more important for the subsequent development of EF during the preschool years.

Garon, Bryson, and Smith (2008) refer to attentional abilities as the foundation of the EF system and argue that studies exploring attentional mechanisms and their relation to EF are needed to develop a comprehensive theory of EF development and change. Although studies implicate orienting behavior in infancy with concurrent regulatory skills (Diaz & Bell, 2010; Morasch & Bell, 2012) and later measures of cognitive development (Rose, Slater, & Perry, 1986), scant research has examined the association between infant attentional abilities and preschool EF, and no studies have done so using a latent variable approach. Another goal of the current study was therefore to investigate the impact that infant attentional skills may have on subsequent levels of EF.

EF Factor Structure and Variations in Developmental Outcomes

Wiebe and colleagues (2011) suggest that another approach towards addressing the question of EF structure may lie in examining the predictive power of different models. Speaking pragmatically, is it more useful to see EF as an umbrella construct or as separate but related abilities when it comes the prediction of outcomes such as social competence and school readiness? The answer to this question has practical implications for interventions designed to target at risk children and theoretical implications for better understanding how EF abilities may work together or separately to support optimal outcomes. Accordingly, another goal of the current study was to examine the predictive power of a one factor model and a two factor model with respect to social skills and school readiness, two important and related developmental outcomes. Research documenting their relation with EF is reviewed briefly below.

Social Skills and School Readiness

The ability to form and maintain interactions with others is a fundamental aspect of child development. Being able to deliberately inhibit one's impulses, given the social demands of the situation, may foster the skills and abilities needed to engage in socially appropriate behavior with one's peers. A large body of literature indicates that well-regulated children are more socially competent, while their less-regulated peers often struggle with social interactions (e.g., Howse, Calkins, Anastopoulos, Keane, & Shelton, 2003).

Research supports the idea that executive function is significantly related to the social skills needed for successful peer interactions; inhibitory control skills seem to be especially predicative of social competency. Preschoolers who were able to inhibit the tendency to touch a prohibited but appealing object were rated as being more effective at navigating social situations by both their parents and their teachers (Raver, Blackburn, Bancroft, & Torp, 1999). Likewise, IC abilities at age 6 and 8 were significantly related to both teacher and parent ratings of social competence and popularity (Spinrad, et al., 2006). Behavior and parent-report ratings of IC abilities significantly predicted third graders' IC abilities both concurrently and two years later

(Lengua, 2003).

Preschool levels of EF predict social competence in kindergarten (Razza & Blair, 2009) and third grade (Gewirtz, Stanton-Chapman, & Reeve, 2009). Fahie and Symons (2003) reported that lower levels of EF in elementary school were significantly related to the presence of parent- and teacher-reported social problems. Limited research indicates that this relationship appears to endure through adolescence. In one longitudinal study (Mischel, Shoda, & Peake, 1988), inhibitory control abilities at age 4 predicted parent-reported social competence more than a decade later; children who were able to delay gratification were rated as having above-average levels of social competence in adolescence. Although the relationship between EF and social competence has been studied at the observed level, the current study was the first to date to examine social skills and EF using a latent variable approach.

Executive functioning abilities also have implications for a separate but related outcome, that of academic performance. Moving from the relatively unstructured lifestyle of the preschool years to a much more structured school environment is challenging for some children. The degree of success that they have with this transition can have a lasting impact on their future educational trajectories, as early success or difficulty in school can significantly impact later academic performance (e.g., McClelland, Acock, & Morrison, 2006).

Numerous studies report a positive relationship between EF and academic performance (e.g., Espy, McDiarmid, Cwik, Stalets, Hamby, & Senn, 2004), especially concerning mathematic performance. It uniquely predicts mathematic performance in preschool (Bull, Espy, & Wiebe, 2008; Espy et al., 2004), kindergarten (Ponitz, McClelland, Matthews, & Morrison, 2009; Welsh, Nix, Blair, Bierman, & Nelson, 2010) and at age 7 (Bull & Scerif, 2001), even after controlling for background variables. Its relationship with reading performance is sometimes not significant once age, vocabulary, parents' level of education, or baseline reading scores are accounted for (e.g., Ponitz, McClelland, Matthews, & Morrison, 2009), although the association between EF and reading has never been studied at the latent construct level.

By far, the bulk of research addressing the relation between mathematics and reading skills and EF has focused on school-age children and only one study has examined the relation between EF and mathematic achievement using a latent analysis approach (Bull, Espy, Wiebe, Sheffield, & Nelson, 2011). The current study was the first to use latent analysis to examine the relationship between EF abilities, mathematic performance, and reading performance in preschool.

A Summary of Research Goals

One of the key unresolved questions about the development of early EF concerns its structure and if it is best defined as a unitary construct or as a set of related yet distinct higher order cognitive abilities. Mounting evidence from studies using confirmatory factor analysis indicates that, in early childhood, at least, it is best represented as a unidimensional construct. A preliminary goal of the current study was to replicate prior research assessing the structure of preschool EF. Specifically, confirmatory factor analysis was used to assess the fit of a unitary and a two factor latent model of EF in a longitudinal sample at ages 2 and 4.

Wiebe and colleagues (2011) suggest that an alternate way to view the nature of EF may lay in examining the predicative value of a unitary model versus fractionated models with respect to developmental outcomes. A second goal of the current study was thus to examine the predicative power of a one factor model with a two factor model with regards to two important developmental outcomes, social competency and school readiness. I predict that a unitary model of EF will be the most useful in terms of examining links between EF and social competency and EF and school readiness. Verbal ability has been linked with academic performance, as well as EF performance, and will therefore be controlled for in these analyses.

A third goal of this study was to examine the longitudinal relationship between infant attention and preschool EF. More general information processing abilities in infancy significantly predicts EF abilities at age 11 (Rose, Feldman, & Jankowski, 2012) and the nature of the relationship between orienting behaviors in infancy and EF skills in early childhood is unknown. Given the rapid development of brain-based attentional and EF networks during infancy and early childhood, infant attention may be even more important for the subsequent development of EF during the preschool years.

In an attempt to extend and integrate research on the structure of EF and factors associated with its development, a final goal was to examine the joint associations between infant attention, preschool EF, social competency, and school readiness.

Method

Participants

One hundred and seventy eight children (90 girls; 28 African American, 136 Caucasian, 14 Hispanic) and their mothers participated in the current study. Participants were part of a larger longitudinal study of cognition and emotion integration across infancy and early childhood and were recruited by two research locations (Blacksburg, VA; Greensboro, NC) using birth announcements and commercial mailing lists of new parent names. Behavioral and physiological data collection took place in the laboratory when participants were 5 months of age (M = 163.24 days, SD = 9.32); additional behavioral data collection took place in the laboratory when the participants were 2 years of age (M = 2 years 4 weeks, SD = 15.13 days) and 4 years of age (M = 4 years 4.4 weeks, SD = 61.96 days). In order to be included for analysis in the current study, participants had to have complete data from both their 5 month visit and age 4 outcome measures, and have completed at least three of the five age 2 EF tasks and at least four of the six age 4 EF tasks. Children had no known neurological conditions or developmental delays. Ninety eight percent of parents had at least a high school diploma. Sixty three percent of mothers had college degrees, as did 51% of fathers. Mothers were approximately 30 years old (range 14-42, SD = 6.23) at the child's birth and fathers were approximately 32.3 years old (range 14-58, SD = 7.50).

Upon arrival at the research laboratory for each visit, written parental consent was obtained and all research procedures were explained. Families were paid at each assessment for their participation. Data were collected in both research locations using identical protocols. Research assistants from both locations were trained together on protocol administration, as well as on behavioral coding. To ensure that identical protocol administration was maintained between the labs, the Blacksburg team periodically viewed DVD recordings files collected by the Greensboro lab. To ensure that identical behavioral coding was maintained between the labs, the Blacksburg team did reliability coding on the Greensboro coding.

5 Month Attention Assessment Measures

Orienting subscale: The Infant Behavioral Questionnaire-revised (IBQ; Garstein & Rothbart, 2003) is a parental-report questionnaire composed of 14 subscales items that measure general patterns of infant behavior. The IBQ is designed for infants between three and twelve months of age and has good reliability and validity across several different populations (Chronbach's Alpha range from 0.77-0.96; Gartstein & Rothbart, 2003; Gartstein, Knyazev, & Slobodskaya, 2005). These 14 subscales consistently load on three broad factors:

Surgency/Extraversion, Negative Affectivity, and Orienting/Regulation. Although all temperament scales were collected, the orienting subscale from the Orienting/Regulation factor was of particular interest. This factor provides a global measure of infants' daily orienting/regulatory behavior in their regular environments, thus capturing behavior that may not emerge in a laboratory setting, and has been significantly related to laboratory measures of infant attention (Rothbart, Derryberry, & Hershey, 2000).

Look Duration: Look duration during infancy is commonly used as an index of attention, with shorter looking durations typically representing more sophisticated ways of processing information. The experimenter showed the infant a glove puppet and look duration was assessed.

Novelty Preference: A preference for novel stimuli over familiar stimuli in infancy is correlated with intelligence in childhood (Rose & Feldman, 1995); novelty preference tasks in infancy are frequently used to assess attention. After being familiarized to a glove puppet, infants were presented with a novel puppet and their looking preference was assessed. Novelty preference was scored a dichotomous variable; participants could either score a 1 (indicating a novelty preference) or a 2 (indicating no preference). Out of the 164 infants who completed this task, 27 showed a preference for the novel glove puppet.

2 Year EF Measures

As described earlier, five previous studies have used confirmatory factor analysis to investigate the structure of EF during the preschool years (Fuhs & Day, 2010; Wiebe, Espy, & Charak, 2008; Hughes, Ensor, Wilson, & Graham, 2010; Wiebe et al, 2011, Miller et al., 2012). Measures used in these five studies were selected to replicate their findings of a unitary factor structure; tasks in the current study are either the same tasks found in these studies or very similar. All measures selected for the current study are additionally developmentally appropriate, used widely within the literature, and have varying non-executive demands.

For all tasks listed, individual interrater reliabilities were calculated for at least 20% of the sample and percent agreement exceeded 95% in all cases.

Tongue Task: The Tongue Task (Kochanska et al., 2000) requires children to hold a goldfish cracker (or an M&M when extra motivation was needed) on their tongue and to inhibit chewing it for increasing intervals of time (i.e., three trials with delays of 10, 20, and 30 seconds). The total administration time for this task was approximately 3 min. This task was videotaped for off-line coding. Performance was coded as either successful (did not chew cracker) or unsuccessful (chewed cracker) and a percentage of successful trials was calculated (i.e., 3 successes = 100%, 2 successes = 67%, 1 success = 33%, 0 successes = 0%).

Pig Bull: The Pig Bull task (e.g., Carlson & Wang, 2007) closely followed the Bear-Dragon procedure described by Carlson and Moses (2001; adapted from Reed, Pien, & Rothbart, 1984), and requires children to follow the instructions given by one puppet and ignore the instructions given by another puppet. The experimenter showed the child the pig puppet, told him or her that this was a nice puppet, and instructed the child to do as the horse said. The experimenter then showed the child the bull puppet, told him or her that this was a mean puppet, and instructed the child to not do as the bull said. The bull trials were the trials of particular interest in this study. Children received two practice trials; children who did not pass the practice trials were not allowed to continue on to the test trials. The final score was a percentage based on the number of successful cow (inhibition) trials (i.e., 4 successes = 100, 3 successes = 75, 2 successes = 50, 1 success = 25, 0 successes = 0.

Shape Stroop: The Shape Stroop task closely followed the Shapes Task described in Kochanska et al. (2000). Children were presented with three pictures of a smaller fruit inside a different larger fruit, such as a small banana inside a large apple, and were asked to identify the smaller fruits. The final score was a percentage based on the number of correct responses divided by the total number of trials.

Ladybugs: The Ladybugs task was modeled after the NEPSY subtest for visual attention (Korkman et al., 1998) and required children to select relevant targets and inhibit irrelevant stimuli. The experimenter showed the child a page with stickers of ladybugs and other stimuli on it; children were told to identify only the ladybugs. The final score was a percentage based on the number of correct responses divided by the total number of targets (ten).

Crayon Delay: The Crayon Delay task (Calkins, 1997) requires children to inhibit the impulse to touch an attractive stimulus when left alone with it. Children were presented with an open box of coloring supplies and were asked if they liked to color. The experimenter told children that she needed to leave the room for a short time, and instructed them not to touch the coloring supplies, box, or paper while she was gone. She then placed the open box and paper within reaching distance of the child and left the room for 120 seconds. Final scores were a percentage based on the total latency (in seconds) to touch the coloring supplies, box, or paper, divided by 120 seconds.

4 Year EF Measures

Gift Delay: The Gift Delay task was adapted from the Wrapped Gift and Gift-In-Bag tasks (Kochanska et al., 2000) and required children to inhibit the impulse to peek at an attractive gift. The experimental wrapped a coloring pad and large box of crayons and told the child to stand with his or her back to the experimenter and not to peek while the gift was being wrapped (60 s). Final scores were calculated as a percentage based on the latency to peek.

Yes/No: Modeled after the Day/Night task (Gerstadt et al., 1994), the child was instructed to say "no" when the experimenter nods her head and to say "yes" when the experimenter shakes her head. Thus, children were measured on their ability to inhibit and override their natural reaction to head nods and shakes. Again, the children were given 2 practice trials, during which they were praised or corrected, and 10 test trials, with 5 head nods and 5 head shakes arranged in a pseudorandom order. The series of stimulus gestures was presented as follows: Y, N, N, Y, N, Y, Y, N, N, and Y. No feedback was given during testing. The total administration time for this task was approximately 3 min. The percentage of correct trials was calculated.

Pig Bull*:* Administration of the Pig Bull task at age four was the same as administration at age two.

Dimensional Change Card Sort: The Dimensional Change Card Sort (DCCS) has been used in the developmental literature to assess EF and rule use in young children (Zelazo, Frye, & Rapus, 1996; Zelazo, Muller, Frye, & Marcovitch, 2003). One set of laminated cards (11 cm×7 cm) was used. There were two target cards (i.e., a blue car and a red flower) to be matched to a series of 14 test cards that displayed the same shape but colors opposite of the target cards (i.e., red cars and blue flowers). The children were first instructed to sort seven test cards by color (pre-switch condition) and then were instructed to switch and to sort the remaining seven test cards by shape (post-switch condition). The dimension (i.e., color or shape) that was relevant during the pre-switch phase was counterbalanced across participants within each age group. In the post-switch condition, the child was reminded of the rule after each trial. However, the child was not told whether or not she sorted the cards correctly; the experimenter simply said, "Okay", and began the next trial. The percentage correct of post-switch sorts was used in these analyses.

BRIEF-P Working Memory Subscales: Parents completed the Behavior Rating Inventory of Executive Function, Preschool Version (BRIEF-P), which assesses everyday executive functioning and is appropriate for children up to age 6. The BRIEF-P is composed of 63 items that load onto the following scales: Inhibit, Shift, Emotional Control, Working Memory, and Plan/Organize; the Working Memory subscale was of particular interest in the current study. Subscale items assess children's daily WM abilities in their natural environment and are rated on a 3-point scale (1 = never, 2 = sometimes, 3 = often). Internal consistency and test-retest stability on the BRIEF-P scales is high and ranges from .80 to .97 and .78 to .90, respectively (Gioia et al., 2003).

Digit Span: The digit span task is typically considered a simple working memory task that measures the phonological loop, or the temporary storage of verbal information. The experimenter repeated sequences of numbers and the child was asked to repeat those numbers back in the same order. The percentage of correct trials was used in these analyses.

4 Year Outcome Measures

Peabody Picture Vocabulary Test (PPVT): The PPVT-III (Dunn & Dunn, 1997) is a nationally standardized assessment of receptive vocabulary and verbal comprehension. Participants' raw scores were used in these analyses.

Vineland Social-Emotional Early Childhood Scale (SEEC): The Vineland SEEC (Sparrow, Cicchetti, & Balla, 2005) is a parent-report questionnaire of children's social skills comprised of three scales: interpersonal relationships, play and leisure time, and coping skills. The three scores are totaled and form a social emotional composite score.

Woodcock–Johnson Psychoeducational Battery III Tests of Achievement: Two subscales from the Woodcock-Johnson (Woodcock & Mather, 2000) were used to assess abilities in mathematics and literacy. The Applied Problems subscale provides an index of mathematical abilities; children must solve word and picture problems and answer questions about time and money. The Letter–Word Identification subscale provides an index of literacy skills; children must name letters from the alphabet and read words. The Woodcock-Johnson is a commonly-used measure of school readiness and academic achievement (e.g., Pontiz, McClelland, Matthews, & Morrison, 2009) and inter-item score reliability among 5 year olds exceeds 0.83 for the Applied Problems subscale and 0.68 for the Picture Vocabulary subscale (Mather & Woodcock, 2001).

Results

The results are listed in five sections. Descriptive statistics for all variables are presented in the first section. The second section presents the results of SEM model testing for both 2 year and 4 year latent EF using MPlus (Version 7; Muthen & Muthen, 2012). The third section details the longitudinal relationship between infant attention and EF at ages 2 and 4, while the fourth section details the longitudinal relationship between 2 year and 4 year EF and 4 year school readiness and social skills. Finally, the fifth section examines the relationships among all of these variables jointly.

Descriptive Statistics

Descriptive statistics for all variables are listed in Table 1. As maximum likelihood estimation techniques assume that data are unstandardized (Kline, 2005), raw scores are used in all analyses. Correlations between infant attention measures, age 2 and age 4 EF, and age 4 school readiness, and social skills are listed in Table 2. Because performance on the Shape Stroop task at age 2 was uncorrelated with other age 2 EF tasks, or indeed any other study variables, it was dropped from all subsequent analyses. To control for the effects of vocabulary on school readiness measures and social skills, residualized scores for age 4 outcome variables were formed by covarying out age 4 vocabulary.

Orienting and novelty preference scores in infancy were marginally correlated ($p < .10$) and were uncorrelated with infant longest look scores. Infant attention variables were uncorrelated with the 2 year and 4 year EF tasks. With the exception of the Shape Stroop, the age 2 EF tasks were significantly correlated with each other. Most age 4 EF variables were significantly correlated with each other, although scores on the BRIEF-P Working Memory were only correlated with performance on the age 4 Pig Bull task. Age 4 math ability was related with two of the age 2 EF tasks and all of the age 4 EF tasks, and age 4 reading ability was related with one of the age 2 EF tasks and four of the age 4 EF tasks. Although age 4 social skills were unrelated to age 2 EF, they were related to three of the six age 4 EF tasks.

Although previous studies have reported a relation between EF and gender (e.g., Wiebe et al., 2008), in the current study gender was only correlated with performance on the Digit Span task and was therefore not included as a covariate in subsequent analyses. Maternal education was examined as a proxy for SES in the current study, but was only correlated with performance on the Crayon Delay task and was therefore not included as a covariate in subsequent analyses.

Outliers and missing data

Variables were screened for nonnormality and the existence of outliers. For each variable, performance scores that deviated from the mean by more than 2.5 SDs from the mean were replaced with values 2.5 SDs from the mean. In the infancy data, this replacement affected four participants' longest look scores and one participant's CBQ Orienting subscale. No data were affected at age 2. At age 4, this replacement affected one participant's Digit Span score, two participants' PPVT scores, and four participants' Vineland scores.

Skewed and kurtotic data were transformed to improve normality using the guidelines suggested by Lei and Lomax (2005). Forty-eight month Pig Bull data were negatively skewed and positively kurtotic; to normalize its distribution, data were first reflected and then inverse transformed. Forty-eight month Yes/No data were positively skewed and were squared to normalize its distribution. Data on all remaining variables fell within the acceptable levels of skew and kurtosis suggested by Lei and Lomax (2005).

Full Information Maximum Likelihood (FIML) estimation was used in analyses; the FIML approach uses all available data and thus maximizes statistical power and estimation accuracy. Little's Missing Completely at Random (MCAR) test (Little, 1988) was used to assess if data was missing completely at random; the non-significant finding indicated that the data did fit a MCAR pattern, ($x^2 = 756.02$, $p > .05$).

Confirmatory Factor Analysis of 2 Year EF

Four age 2 EF variables remained after dropping the Shape Stroop task. This number of variables precluded the possibility of testing the hierarchical structure of age 2 EF, so data were analyzed with a unidimensional CFA with all manifest variables (Tongue Task, Pig/Bull, Ladybug task, Crayon Delay) loading on the latent General EF factor.

The chi-square statistic, the CFI, the RMSEA, and the SRMR were all used to evaluate model fit. The chi-square statistic indexes the discrepancy between the hypothesized covariance matrix and the true covariance matrix; as the chi-square increases, model fit worsens. For this reason, it is sometimes referred to as a 'badness of fit' statistic; a non-significant value indicates that the hypothesized model is supported by the sample matrix. The comparative fit index, or CFI, indicates the extent to which the proposed model fits the data compared to the baseline/population model. Values range from 0.00 to 1.00, and values of .95 or above are generally considered to indicate good fit (Hu & Bentler, 1999). The Root Mean Square Error of Approximation, or RMSEA (Steiger & Lind, 1980) also measures how well the hypothesized model fits the data. Like the chi-square, the RMSEA is sometimes called a 'badness of fit' statistic, as higher values correspond with worse fit. Values at or below .05 are considered to indicate good fit and values at or below .08 indicate acceptable fit (Schumacker & Lomax, 2004); MPlus reports a 90% confidence interval around RMSEA values, providing the researcher with a means of assessing the precision of this estimate. The standardized root mean square residual, or SRMR, computes the correlation matrices of both the hypothesized and the sample model and indexes the mean absolute correlation residual. Values below .10 are considered to indicate good fit.

The unitary model was a good fit for the data ($x^2(2) = 0.03$, $p = .98$; CFI = 1.00; RMSEA = .00; SRMR = .00; see Table 3). All four tasks had significant factor loadings (see Figure 1 and Table 4 for standardized parameter estimates). Unexpectedly, the Pig Bull task loaded negatively on latent age 2 EF. Error terms for the manifest indicators, which denote the unexplained variance, or the variance that is not explained by the hypothesized pathways, are also listed in Table 4.

Model Testing of 4 Year EF

Bifactor Model Testing*:* A bifactor model was used to test the unity and diversity of EF at age 4 as this type of modeling can test multifaceted constructs. In bifactor modeling, each task loads simultaneously on the general factor and on the specific factor it is hypothesized to represent.

It was hypothesized that scores on the age 4 battery could be explained by a general factor (General EF) as well as the specific factors of Inhibitory Control and Working Memory (see Figure 2 for the hypothesized bifactor model). Each of the six manifest indicators loaded only on the general factor and its specific factor; none of the latent factors were allowed to correlate. For the purpose of identifying the model, one of the factor loadings in each of the three latent variables (General EF, Inhibitory Control, and Working Memory) was set to one. Because all six variables were on different scales, they were rescaled and divided by a constant to bring the variances between 0-10 to help with model convergence when necessary.

The bifactor model was inadmissible, however, as the standard errors could not be computed. Because results from the bifactor model were inadmissible, a second order model was conducted as an alternative approach to test the structure of EF at age 4.

Second Order Model Testing: Like bifactor models, second order models can be used to test multifaceted constructs. Unlike bifactor models, however, second order models do not separate the higher order factor from the lower order factors and so cannot be used to determine if a first order factor still exists independent of the general factor or if it is entirely absorbed by the general factor. When second order constructs are hypothesized to be comprised of two specific factors, as with the current study, models will only be identified if the second order factor loadings are constrained to be equal, or if the model is tested in the context of a larger model that can accommodate it.

To identify the second order model, each manifest indicator loaded on the first order factor it was hypothesized to measure (either Inhibitory Control or Working Memory) and did not load on the other first order factor; to identify the model, loadings of the general factor were constrained to be equal. (See Figure 3 for the hypothesized second order model). Results from the second order model were inadmissible, however, due to negative residual variance (indicating model misspecification) from one of the factors.

Nested Model Testing: Because the results from the second order were inadmissible, nested model testing was conducted as an alternate means of evaluating the fit of a unitary factor solution versus a two factor solution. Two 2 factor models were estimated, one with the correlation between the Working Memory and Inhibitory Control latent variables fixed to 1 and the other with that correlation freed to be estimated (see Figure 4 for the hypothesized factor models). A two factor model with the intravariable correlation fixed to 1 indicates that the two latent variables are perfectly identical and are essentially a single latent variable; because this model represents a restricted version of the two factor model with the intravariable correlation freed to be estimated, relative model fit can therefore be evaluated with the chi-square difference test.

For both models, however, the results were inadmissible due to negative residual variance, indicating model misspecification.

One Factor and Two Factor Model Testing: Because the nested models did not converge normally, a one factor CFA and a two factor CFA were conducted to compare model fit. The one factor model consisted of one latent variable, General EF, with all six EF manifest variables loading on General EF. The two factor CFA consisted of two latent variables, Working Memory and Inhibitory Control, with the DCCS, Digit Span, and BRIEF-P Working Memory scale loading on the WM variable and the Gift Delay, Yes/No task, and Pig Bull task loading on the IC factor. Results from the two factor CFA, however, indicated linear dependency in that the two latent factors had a correlation above 1, rendering the model inadmissible.

The one factor model, however, fit the data with no convergence problems. Fit statistics indicated good model fit ($x^2(9) = 9.40$, $p = .40$; CFI = .99; RMSEA = .02; SRMR = .04; see Table 3). Factor loadings for all six manifest indicators (presented in Table 5 and Figure 5) were significant and in the expected direction.

Infant Attention and Later Executive Function

The relation between attention in infancy and later EF skills was next assessed. Age 2 EF and age 4 EF (controlling for age 2 EF) were regressed on 5 month attention. The model was first run with the three 5 month attention variables loading on a latent attention variable, but none of the attention variables significantly loaded on the latent attention variable, and so the model was rerun with the 5 month attention variables treated as separate manifest indicators.

Although the overall model was a good fit for the data ($x^2(58) = 57.10$, $p = .51$; CFI = 1.00; RMSEA = .00 (90% CI .00-.05); SRMR = .06; see Table 3), the path coefficients from 5 month attention variables to age 2 EF and to age 4 EF were not significant (see Table 6 and Figure 6 for standardized parameter estimates). The path from age 2 EF to age 4 EF was significant, however, and as expected, factor loadings of the manifest indicators on latent age 4 EF were all significant (except for BRIEF-P Working Memory, p=.06) and in the expected direction. As with the unitary model of age 2 latent EF, the loading for the Pig Bull task (age 2) was in the opposite direction as originally expected.

The r-squared value represents the amount of variance explained in a dependent variable by its covariates and is also shown in Table 6. Infant attention explained no significant variance in age 2 EF, but 59% of the variance in age 4 EF was explained by infant attention and age 2 EF. Although MPlus currently does not parse out the variance explained in dependent variables by their individual covariates, rather giving the total variance explained *jointly* by the covariates, it is likely that infant attention contributes very little, if anything, to the variance in age 4 EF, given the non-significant pathways between infant attention measures and age 4 EF and the significant 0.77 standardized loading of age 2 EF on age 4 EF.

To determine the variance in age 4 EF performance explained solely by infant attention, rather than by infant attention and age 2 EF performance, a model was conducted with age 4 EF regressed only on infant attention. The model was an adequate fit for the data, ($x^2(24) = 27.65$, $p = .28$; CFI = 0.90; RMSEA = .03 (90% CI .00-.07); SRMR = .05, but none of the attention variables loaded significantly on age 4 performance and they did not contribute significantly to variance in age 4 EF scores , $p = .81$.

EF and School Readiness and Social Skills

Next, hypothesized relationships among age 2 and age 4 EF and outcome variables were tested. General EF at age 4 was regressed on age 2 EF, and the outcomes of math ability, reading ability, and social skills were regressed on both age 2 and age 4 EF performance. This model was a good fit for the data ($x^2(58) = 69.63$, p=.14; CFI = .94; RMSEA = .03 (90% CI .00-.06); SRMR = .06; see Table 3). Pathways from age 4 EF and social skills and math ability were all significant and in the expected direction, and the pathway to reading ability was marginally significant, p=.07. In contrast, pathways from age 2 EF and reading ability, math ability, and social skills were nonsignificant. (See Table 7 and Figure 7 for standardized parameter estimates.)

The r-squared values for manifest variables and latent age 4 EF are also presented in Table 7. Forty five percent of the variance in latent age 4 EF was explained by age 2 EF.

Infant Attention, Later Executive Function, and Outcome Variables

A final model examined the longitudinal relationships between infant attention, EF at ages 2 and 4, and outcome variables at age 4. General EF at age 4 was regressed on age 2 EF and infant attention variables, and age 4 social skills, reading ability, and math ability were regressed on age 4 EF.

This model was a good fit for the data ($x^2(82) = 88.45$, p=.29; CFI = .96; RMSEA = .02 (90% CI .00-.05); SRMR = .06; see Table 3). As expected, latent 2 year EF loaded significantly on latent 4 year EF, and manifest indicators for each latent EF variable demonstrated the same pattern of loadings as they had in prior models. None of the paths from age 2 EF to age 4 outcome variables were significant, but paths from age 4 EF to school readiness measures were significant and in the expected direction, and the path from age 4 EF to social skills was marginally significant, p=.07. (See Table 8 and Figure 8 for standardized parameter estimates.)

The r-squared values for latent age 2 EF and latent age 4 EF are also presented in Table 8. Age 4 EF predicted sixty percent of the variance in infant attention, age 2 EF, age 4 social skills, and age 4 reading and math skills.

Discussion

There were four main goals to this study: 1) to evaluate the structure of EF at ages 2 and 4, 2) to examine the longitudinal relations between infant attention and later EF, 3) to examine the relations between EF at ages 2 and 4 and outcomes at age 4, and 4) to examine the relationships among all of these variables jointly.

Prior research indicates that preschool EF is best explained as a unitary construct, and I therefore hypothesized that a unitary model of EF would be a good fit for performance at both ages 2 and 4. Based on theoretical support for the role of attention in EF (e.g., Garon, Bryson, & Smith, 2008) and given the rapid development of brain-based attentional and EF networks during infancy and early childhood, I hypothesized that attentional skills in infancy would relate to toddler and preschool EF. I additionally hypothesized that a unitary model of EF would predict social competency and school readiness at age 4. I finally hypothesized that relations between infant attention, EF, social competency, and school readiness would hold when all these variables were entered into the same model.

I found support for a unitary model of EF at ages 2 and 4, but found no support for infant attention measures as significant predictors of later EF. While age 2 EF failed to predict any outcome measures at age 4, pathways between age 4 EF and all age 4 outcomes were significant. Although factor loadings changed in the full model, their direction and significance remained unchanged. These findings are discussed in greater detail below.

Latent EF Structure at Ages 2 and 4

Working memory and inhibitory control are widely believed to play key roles in successful EF deployment; the extent to which they represent unitary or dissociable abilities is an unresolved issue within the literature. Recent studies have turned to factor analytical techniques for investigating the underlying nature of EF. Measurement error can substantially bias empirical conclusions (Fuller, 1987) and CFA therefore explicitly models error terms so that observed variables reflect both the true score and measurement error. A latent variable approach additionally extracts only *common* variance among tasks with different non-executive requirements, providing a more accurate reflection of genuine EF performance.

The first goal of the current study was accordingly to examine the structure of EF at ages 2 and 4 with confirmatory factor analysis. Although adult EF is best characterized by both unity and diversity (Friedman et al., 2008, 2011, 2012), mounting evidence indicates that in early childhood it is best represented as a unidimensional construct (Fuhs & Day, 2010; Wiebe, Espy, & Charak, 2008; Hughes, Ensor, Wilson, & Graham, 2010; Wiebe et al, 2011). It was therefore hypothesized that a unitary model would best explain performance on a battery of EF tasks among children of these ages.

At age 2, data were analyzed with a unidimensional CFA with all manifest variables (Tongue Task, Pig/Bull, Ladybug task, Crayon Delay) loading on the latent General EF factor. Tasks all varied in terms of their requirements and format. One task, the Stroop Task, failed to correlate with any other EF variables or to load on a latent EF factor and was therefore dropped from further analyses. The resulting number of variables precluded the possibility of testing the hierarchical structure of EF, but it was still possible to test the existence of a latent construct. Although alternate models of EF were unable to be tested, a one-factor model provided an exceptional fit for the data and provides further confirmation for the unidimensional nature of EF in early childhood.

These results are consistent with findings from prior CFA studies of older children and additionally extend such research by examining performance a year younger than other CFA study. By far, the bulk of research on childhood EF has focused on the ages between 3 and 5, a time of dramatic improvement in EF abilities (e.g., Carlson, 2005; Diamond, 2002; Diamond & Taylor, 1996), and the developmental literature has largely neglected the age right before this dramatic improvement in EF functioning. This has had bleak consequences for our knowledge about EF development during this time; Diamond (2002) asserts that we know the least about EF developments during the ages of two and three than during any other time. The sparse research on EF abilities at age 2 does not stem from a lack of interest on the part of researchers, as the second year of life seems to be an important transitional time for language development and self regulatory skills, but rather from the difficulties that come with administering tasks to very young children. Although a variety of tasks have been used to assess EF in older children, many tasks are not developmentally appropriate for 2 year olds (Carlson, 2005), and researchers who have attempted to collect data during this age (e.g., Diamond & Taylor, 1996) have often discontinued testing due to the difficult demands of tasks used relative to the age of the participants. The lack of studies examining EF at age 2 precludes firm conclusions about the nature of its structure; of the few studies that have traced EF development during this time, most only collect data at a single time point, commonly 24 months of age (e.g., Hughes & Ensor, 2005; McGuigan & Nunez, 2006; Zelazo, Reznick, & Spinazzola, 1998), and none have done so with a latent analysis framework. The longitudinal nature of this study extends prior research in this area by demonstrating that EF performance at this age can be characterized by unity.

The number of tasks children completed at age 4 allowed for hierarchical model testing, and several different models were computed. A bifactor model was first tested as this type of modeling can test multifaceted constructs; each task loaded simultaneously on the general factor (i.e., General EF) and on the specific factor it was hypothesized to represent (Working Memory or Inhibitory Control). The bifactor model was inadmissible, however, as the standard errors could not be computed. A second order model was next tested as an alternative approach to test multifaceted constructs, but results from the second order model were inadmissible due to a non positive psi matrix. Nested model testing was next conducted as an alternate means of evaluating the underlying structure of age 4 EF, but for both models, the psi matrix was nonpositive definite and thus the results were inadmissible. Ultimately, the only model to fit the data with no convergence problems was the unitary model; fit statistics indicated good model fit, and all tasks loaded in the expected direction on the latent EF variable, with factor loadings ranging from 0.27 (p = .02) for the Yes/No task, to 0.55 (p = .02) for the DCCS task.

Tasks used at both ages appeared to be developmentally appropriate, without floor or ceiling effects, and all tasks at both ages loaded significantly on their respective latent EF variables. The pathway between age 2 and age 4 EF was estimated and was significant with a factor loading of .70 (p = .00) when just the two latent EF variables were included in the model and a factor loading of .40 (p = .00) in the final model with infant attention and outcome variables included. An examination of the mean tasks scores at age 2 and at age 4 reveals the expected finding that mean task performance scores were higher at age 4 compared to age 2, although the lack of continuity in tasks from age 2 to age 4 precluded the possibility of testing for measurement invariance. Results from both the age 2 and age 4 data supported the hypothesis of the unitary nature of EF during early childhood and indicate that executive functioning abilities during this time show strong signs of continuity in terms of underlying structure.

The lack of similar tasks at age 2 and age 4 highlights one of the challenges existent in the measurement of EF skills in young children; many tasks are only appropriate for children of a relatively narrow age range and demonstrate ceiling or floor effects quickly (Carlson, 2005). Because a central issue in developmental psychology concerns the study of developmental change, an accurate interpretation of changes in task performance is dependent upon the assumption of measurement invariance being met. Measurement invariance over time refers to the critical assumption that tasks are measuring the same ability in all participants at all time points and is therefore particularly relevant to the study of childhood executive functioning, as EF tasks are often only suitable for a narrow age range (Carlson, 2005). If measurement invariance over time cannot be established, this indicates that tasks are not assessing the same construct in the same way at different time points, and makes the interpretation of age-related changes in performance problematic (Cheung & Rensvold, 2002). The lack of an age-appropriate battery of EF tasks normed for children across several years limits the ability to achieve a thorough understanding of age-related changes in the development of EF. This is an area for future efforts to focus on, as an age-appropriate battery of tasks designed for the early childhood period would be invaluable to researchers who seek to better understand developmental changes.

Infant Attention and Later EF

Posner and Rothbart's developmental framework of attention posits that attention systems play a key role in EF and the related construct of Effortful Control, and in their meta analysis of preschool EF, Garon, Bryson, & Smith (2008) maintain that attention plays a pivotal role in EF development during this time. Despite conceptual support for the idea that attention is related to EF, however, the impact of infant attention on later EF is a largely unexplored area. Accordingly the second goal of this study was to examine the relations between infant attention and later EF.

Three commonly-used measures of infant attention were used. Two were laboratory-based measures; infants' longest look at a video and their degree of novelty preference. The Orienting subscale from the Orienting/Regulation factor on the IBQ was used to index global orienting behaviors in everyday situations. Because none of these tasks loaded on a common latent Infant Attention factor, they were treated as separate manifest indicators and paths from each infant attention indicator to both 2 year and 4 year EF were estimated. The three infant attention tasks were largely uncorrelated with other variables in the study; no attention tasks were correlated with age 2 EF measures, and only 5 month longest look scores were correlated with one age 4 EF task, scores on the Working Memory scale of the BRIEF-P. Only scores on the 5 month Orienting subscale were correlated with one of the outcome variables, age 4 social skills. Five month novelty preference scores were uncorrelated with any study variables.

Contrary to my hypothesis, none of the pathways from infant attention variables to later EF were significant, nor were any of the pathways to age 4 outcome variables. This lack of significant pathways from infant attention variables to later EF and social and academic outcomes was unexpected, given both conceptual (e.g., Derryberry & Rothbart, 1997) and empirical (e.g., Espy & Bull, 2005) support for the relation between attention and EF. Although it is possible that there truly is no relation between these two constructs, it seems more likely that other factors are at play. One possibility is that infant information processing skills in general, rather than specific attentional skills, may be associated with later EF. Infant attention at five months may additionally be too fractionated at five months to have a significant relationship with later EF. It is also possible that more involuntary forms of attention that manifest in the first months of life play a far less central role in later EF development than more voluntary forms of attention. Each of these possibilities is discussed below.

In infancy, more general information processing skills, rather than specific attentional skills, may be associated with later EF. Information processing abilities include attention, processing speed, and memory skills, and are a source of individual differences in EF performance among older children (e.g., Kail, 2007) and adults (e.g., Salthouse, 2005). A recent study suggests that they might likewise underlie differences in EF performance in infancy. Rose, Feldman, and Jankowski (2012) examined the predicative power of infant attention, processing speed, and memory on EF performance at age 11. Although models relating overall infant information processing abilities to age 11 EF showed good fit, pathways from infant attention variables to later EF were *not* significant. In contrast, pathways from infant processing speed and memory variables to later EF were significant.

It also possible that infant attention is simply too fractionated at five months of age to make significant contributions to later EF. The lack of correlation among the three infant attention tasks supports this idea; tasks as well additionally failed to load on a common latent variable, indicating that they share little common variance. Similar findings regarding a lack of relation between attention measures in early infancy have been reported in other studies. In a 2006 study, for example, Kannas, Oakes, and Shaddy report that attention measures were uncorrelated with each other at 7 and 9 months of age, but were correlated by 31 months of age.

Garon, Bryson, and Smith (2008) suggest that attentional skills become more cohesive and unitary over the course of early childhood, starting late in the first year of life.

It is also possible that more involuntary forms of attention that manifest in the first months of life play far less of a central role in later EF development than more voluntary forms of attention. The bulk of the research examining possible attention-related contributions to individual differences in EF performance have focused on the role of executive attention, whereas the three attention tasks used in the current study all index orienting behaviors. Orienting behaviors are commonly assumed to represent more involuntary, automatic attentional responses; in contrast, executive attention behaviors are commonly assumed to represent more focused, voluntary attention. Executive attention allows children to selectively attend to environmental and internal stimuli that are compatible with their goals and tasks, while ignoring incompatible stimuli; young infants struggle with this. Resolving mental conflicts while processing information, as well as shifting one's attention to meet task demands, are central components of EF and are supported by the anterior attention system (Rothbart & Posner, 2001).

As attentional control shifts from being more involuntary (i.e., orienting behavior) to more voluntary (i.e., executive attention) in nature, children see a dramatic increase in their EF skills. Although some studies have examined the development of orienting behavior, one unresolved issue concerns the longitudinal relation between orienting and executive attention behavior. How these forms of attention unfold and become integrated (and the degree to which they maintain separate trajectories) over the course of early childhood remains unknown.

Age 2 and 4 EF and Age 4 Outcomes

After examining the structure of EF at ages 2 and 4 and its relation with infant attention, I assessed its relation with age 4 math and reading ability and social skills. A fundamental aspect of child development concerns the ability to form and maintain interactions with one's peers, and research indicates that well-regulated children are more socially competent than their less-regulated peers. Optimal social interaction with peers involves conscious control of one's behavior and the ability to deliberately inhibit one's impulses according to the social demands of the situation. Likewise, children with adequate regulatory abilities often fair better in school, while those who struggle with inhibitory control are at risk for less than optimal academic outcomes (Grolnick & Slowiaczek, 1994; Normandeau & Guay, 1998). The ability to follow directions, especially in the face of distractions, and to work independently to complete tasks are vital components of school success (M (McClelland, Morrison, & Holmes, 2000; Rimm-Kaufman, Pianta, & Cox, 2000). The degree of success that children have as they transition from the relatively unstructured lifestyle of the preschool years to a much more structured school environment can have a lasting impact on their future educational trajectories, as early success or difficulty in school can significantly impact later academic performance (e.g., McClelland, Acock, & Morrison, 2006).

Although age 2 EF performance failed to predict any of the age 4 outcome variables, age 4 EF significantly and positively predicted all three outcome variables, with factor loadings ranging from 0.62 for reading ability (p =.00) to 0.79 for math ability ability (p =.00). Given the strong relation between age 2 and age 4 EF, it is surprising that pathways from age 2 EF to age 4 outcomes were not significant.

The finding that EF ability is related to mathematic abilities is consistent with prior research. The relationship between EF and mathematic performance is a robust one at the manifest variable level (e.g., Bull & Scerif, 2001). EF abilities uniquely predict mathematic performance in preschool (Bull, Espy, & Wiebe, 2008; Espy et al., 2004), kindergarten (Ponitz, McClelland, Matthews, & Morrison, 2009; Welsh, Nix, Blair, Bierman, & Nelson, 2010) and at age 7 (Bull & Scerif, 2001), even after controlling for background variables. Results from this study provide further support for the idea that this relation is also robust at the latent variable level, as only one prior study has assessed this relation using a CFA framework. EF abilities include the ability to focus on certain mental information while manipulating that information, and this type of higher-order processing also plays a key role in solving mathematics problems (such as word problems involving addition or subtraction). Focusing on relevant information and inhibiting distractions from nonessential information are essential skills needed for both successful EF deployment and mathematics skills development.

Although the relation between EF and mathematic performance is well-documented, traditionally the relation between EF and reading performance has been more ambiguous. Although several studies report a relation between EF and literacy skills (e.g., McClelland, Cameron, Connor, et al., 2007), this relationship is sometimes not significant once age, vocabulary, parents' level of education, or baseline reading scores are accounted for (e.g., Ponitz, McClelland, Matthews, & Morrison, 2009), and difficulties in reading comprehension have additionally been linked with a variety of factors beyond executive function skills, such as lack of reading fluency (Perfetti, Marron, & Foltz, 1996) and oral language proficiency (Catts, Fey, Zhang, & Tomblin, 1999). One study examined the contributions of individual differences in EFs, attention, reading fluency, and vocabulary size to reading comprehension and found that EFs were a significant and unique predictor (Sesma, Mahone, Levine, Eason, & Cutting, 1999).

The relation between EF skills and social skills was an expected one, as successful deployment of both abilities involves the ability to deliberately inhibit one's impulses according to the social demands of the situation. Conscious control of one's behavior, particularly when the appropriate behavior conflicts with a prepotent response, requires the use of inhibitory control abilities. Because children with poor social skills are more likely to experience rejection from their peers, which may limit future social encounters that could potentially result in learning socialization skills, a practical application of this knowledge could be incorporated into interventions designed to improve EF skills in at-risk children by improving EF skills within a social framework. Diamond notes in her 2012 review on school curricula and activities for improving EF that interventions and programs that have yielded the most benefits also address children's emotional and social needs.

Limitations

Several limitations should be noted. Firstly, study design precluded the possibility of testing a hierarchical model of EF at age 2. Because performance on the Shape Stroop task at age 2 was uncorrelated with any other study variables, it was dropped from all subsequent analyses, leaving four age 2 EF variables. Age 2 data were therefore analyzed with a unidimensional model only. The general trend in SEM research on childhood EF suggests a unitary pattern in early childhood, with differentiation of EF components occurring in middle childhood and adolescence, and the findings of this study support this trend. Nevertheless, it should be noted that study design eliminated the possibility of testing nested models of EF at age 2.

With regards to the finding that infant attention failed to predict later EF, it is possible that the low rate of novelty preference in this particular sample rendered this measure an ineffective gauge of infant attention. Only 27 infants out of the 164 who completed the novelty preference task preferred the novel stimuli. (As previously stated, novelty preference was defined as looking preference at either a familiar puppet or a novel one, and is a commonly-used measure of infant attention.)

Novelty preference was only one of three infant attention variables. The other two variables (longest look, orienting) also failed to predict later EF. It may be the case that *changes* in early infant attention may be more predicative of later regulatory capacities than static abilities (i.e., performance measured at only one time point, as in the current study). Bridgett et al. (2011) report that changes in orienting abilities (as measured by the IBQ), rather than static levels of orienting ability, significantly contributed to toddler Effortful Control, a construct closely related to EF, and it is possible that examining the rate of change in infant attention may have yielded a different picture with respect to subsequent EF abilities. Likewise, more involuntary forms of attention that manifest in the first months of life, such as the type of attention captured in the tasks used in the current study, may play far less of a central role in later EF development than more voluntary forms of attention.

Future directions

The lack of similar tasks at age 2 and age 4 highlights one of the challenges existent in the measurement of EF skills in young children; many tasks are only appropriate for children of a relatively narrow age range and demonstrate ceiling or floor effects quickly (Carlson, 2005). Because a central issue in developmental psychology concerns the study of developmental change, an accurate interpretation of changes in task performance is dependent upon the assumption of measurement invariance being met. Measurement invariance over time refers to the critical assumption that tasks are measuring the same ability in all participants at all time points and is therefore particularly relevant to the study of childhood executive functioning, as EF tasks are often only suitable for a narrow age range (Carlson, 2005). If measurement invariance over time cannot be established, this indicates that tasks are not assessing the same construct in the same way at different time points, and makes the interpretation of age-related changes in performance problematic (Cheung & Rensvold, 2002). The lack of an age-appropriate battery of EF tasks normed for children across several years limits the ability to achieve a thorough understanding of age-related changes in the development of EF. This is an area for future efforts to focus on, as an age-appropriate battery of tasks designed for the early childhood period would be invaluable to researchers who seek to better understand developmental changes.

Although some efforts recently have focused on developing a comprehensive battery of EF tasks that are suitable for a variety of ages, such as the Cognition Battery of the NIH Toolbox (Zelazo & Bauer, 2013), most tasks assessing the early childhood period are normed for participants ages 3 and older, making it difficult to find a variety of developmentally appropriate tasks to use on younger children. One factor to take into account when examining EF development in early childhood is that EF tasks for very young children call on other abilities, such as language comprehension and fluency. The use of structural equation modeling can account for measurement error caused by such nonexecutive task demands. EF researchers have only recently begun to focus on psychometric research, and the field will benefit greatly from the inclusion of age-appropriate tasks normed for children under the age of 3.

General Conclusions

This research centered on an examination of the structure of latent EF at two different time points and incorporated a variety of potential predictors and outcome measures, using both laboratory measures and questionnaire data to offer a more complete view of development. Latent analysis indicated that a unitary model of EF best describes preschoolers' performance at ages 2 and 4, supporting a growing body of research indicating the unidimensional nature of EF in early childhood, and confirmed that EF abilities are significantly associated with both social and academic development. Understanding the nature of EF and the factors associated with optimal regulatory abilities is necessary for both theoretical and practical purposes, and given the considerable improvements that happen to EF abilities in early childhood, longitudinal studies such as this one are necessary to address issues of developmental change. As developmental change is a within-person phenomenon, it is accordingly best studied with longitudinal research (Molenaar, Huizenga, & Nesselroade, 2003). The majority of studies that have examined the structure of EF have done so in only one age group, or have collapsed different age groups into one, thus limiting conclusions that can be drawn regarding developmental changes.

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Table 1
Descriptive Statistics for all Variables in the Study

Variable	N	Range	M	SD
5 months				
Longest Look	168	2.17-66.53	9.32	7.85
Orienting Subscale	164	1.17-6.57	4.16	1.03
Novelty Preference	127	1.00 or 2.00	21.3%	---
Age 2				
Tongue Task	145	0.00-3.00	1.20	1.27
Pig Bull	109	0.00-4.00	2.60	1.58
Shape Stroop	150	0.00-6.00	2.86	1.77
Ladybugs	161	0.00-10.00	5.38	2.84
Crayon Delay	169	0.00-60.00	14.76	22.62
Age 4				
Gift Delay	175	1.00-5.00	3.58	1.60
Yes/No	156	0.00-20.00	15.26	5.74
Pig Bull	170	0.00-4.00	3.50	1.22
DCCS	176	0.00-6.00	3.37	2.77
BRIEF-P WM Scale	176	17.00-36.00	24.84	5.32
Digit Span	162	1.00-6.00	3.89	0.79
Verbal Ability	174	33.00-180.00	81.79	18.50
Social Skills	177	48.00-190.00	128.14	23.93
Math Ability	177	2.00-20.00	12.57	3.94
Reading Ability	177	2.00-19.00	8.13	4.36

Note. Novelty Preference was a dichotomous variable and so no standard deviation value is given. The mean value represents the percentage of participants who demonstrated a novelty preference.

Table 2

Correlations for All Variables in the Study

Variable	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17
5 months																	
1. Orient	1																
2. Long Look	.06	1															
3. Nov. Pref	$.15^{t}$	.02	1														
Age 2																	
4. TT	-.05	.01	.09	1													
5. Pig Bull	.09	-.10	.01	**-.23***	1												
6. Ladybugs	.07	-.06	-.04	**.18***	**-.28****	1											
7. Shp. Stroop	-.05	.10	-.07	.10	.09	.04	1										
8. Cray. Delay	-.09	.01	.07	**.19***	**-.29****	**.22****	-.07	1									
Age 4																	
9. DCCS	-.07	-.05	-.01	.10	**-.21***	**.38****	-.04	**.19***	1								
10. Digit Span	.08	-.03	.03	.03	.01	.10	-.02	.08	**.22****	1							
11. Yes/No	-.07	.11	.07	.01	.01	-.01	.03	.10	.14	.11	1						
12. Pig Bull	.10	-.09	-.03	.02	-.02	**.20***	.08	.03	**.28****	**.23****	.05	1					
13. WM	. 06	**.19***	.01	.12	**-.19***	**.20***	.01	-.03	.11	$.14^{t}$	.03	**.25****	1				
14.Gift Delay	-.13	-.07	-.08	**.17***	-.04	**.21****	.09	.07	**.26****	**.20***	$.15^{t}$	.07	.06	1			
15. Verbal	-.06	.01	.01	.03	-.21*	.28**	.04	.22**	.46**	.17*	.23**	.27**	$.13^{t}$	.11	1		
16. Soc. Skills	**.19***	-.01	.07	.01	.06	.09	-.03	-.03	**.24****	$.15^{t}$	.11	**.33****	.26**	.09	**.27****	1	
17. Reading	.05	-.09	.02	$.16^{t}$	-.07	**.25****	.03	.11	**.40****	**.37****	**.19***	$.14^{t}$	.08	**.16***	**.45****	.12	1
18. Math	-.11	-.08	.05	.11	**-.22***	**.39****	.08	**.15***	**.56****	**.27****	**.25****	**.32****	**.15***	**.22****	**.53****	**.24****	**.5[illegible]**

Note. Nov. Pref = Novelty Preference. TT = Tongue Task. Shp Stroop = Shape Stroop. Cray Delay = Crayon Delay. WM = BRIEF-P Working Memory scale. Verbal = PPVT scores. Soc Skills = Vineland scores. Reading = Woodcock Johnson Letter Word Identification scores. Math = Woodcock Johnson Applied Problems scores.

* $p < .05$. ** $p < .01$. $^{t}p < .10$.

Table 3

Fit Indices for Age 2 and Age 4 EF Models

Model	χ^2	df	*p*	CFI	RMSEA	SRMR
Age 2 unitary model	0.03	2	.98	1.00	.00	.00
Age 4 unitary model	9.40	9	.40	.99	.02	.04
Age 2 and 4 EF on 5mo attn	56.82	58	.52	1.00	.00	.06
Age 2 and 4 EF on 4yr outcomes	69.63	58	.14	.94	.03	.06
5mo attn., age 2 and 4 EF, and 4yr outcomes	88.45	82	.29	.96	.02	.06

Table 4

Standardized Parameter Estimates of Age 2 EF Unitary Model

Parameter	Estimate	*SE*	*p*
Age 2 Factor Loadings			
Tongue Task	.38	.11	.00
Pig Bull	-.63	.13	.00
Lady Bugs	.47	.11	.00
Crayon Delay	.47	.11	.00
Residual variances			
Tongue Task	.85	.08	.00
Pig Bull	.60	.16	.00
Lady Bugs	.78	.10	.00
Crayon Delay	.78	.10	.00

Table 5

Standardized Parameter Estimates of Age 4 EF Unitary Model

Parameter	Estimate	*SE*	*p*
Age 4 Factor Loadings			
DCCS	.55	.10	.00
Digit Span	.47	.10	.00
Yes/No	.27	.11	.02
Gift Delay	.37	.10	.00
BRIEF-P WM Scale	.29	.10	.00
Pig/Bull	.47	.10	.00
Residual Variances			
DCCS	.70	.11	.00
Digit Span	.78	.10	.00
Yes/No	.93	.06	.00
Pig/Bull	.87	.07	.00
BRIEF-P WM Scale	.92	.06	.00
Gift Delay	.77	.10	.00

Table 6

Standardized Parameter Estimates of the Bidirectional Longitudinal Pathways Between Infant Attention and EF at Ages 2 and 4

Parameter	Estimate	*SE*	*p*
Age 2 EF Factor Loadings			
Tongue Task	.29	.11	.01
Pig Bull	-.41	.12	.00
Ladybugs	.71	.10	.00
Crayon Delay	. 38	.10	.00
Age 2 EF on 5mo Longest Look	-.08	.12	.54
Age 2 EF on 5mo Novelty Score	.01	.11	.96
Age 2 EF on 5mo Orienting	.03	.11	.77
Age 4 EF Factor Loadings			
DCCS	.68	.08	.00
Digit Span	.37	.10	.00
Yes/No	.22	.11	.05
Gift Delay	.40	.09	.00
BRIEF-P WM Scale	.20	.10	.06
Pig/Bull	.42	.09	.00
Age 4 EF on Age 2 EF	.75	.12	.00
Age 4 EF on 5mo Longest Look	.00	.11	.99
Age 4 EF on 5mo Novelty Score	-.02	.10	.84
Age 4 EF on 5mo Orienting	-.06	.11	.60
Residual Variances			
Age 2 Tongue Task	.92	.06	.00
Age 2 Pig Bull	.83	.10	.00
Age 2 Ladybugs	.49	.15	.00
Age 2 Crayon Delay	.85	.08	.00
Age 4 DCCS	.54	.11	.00
Age 4 Digit Span	.86	.07	.00
Age 4 Yes/No	.95	.05	.00
Age 4 Gift Delay	.84	.07	.00
Age 4 BRIEF-P WM Scale	.96	.04	.00
Age 4 Pig/Bull	.82	.08	.00
Age 2 EF	.99	.02	.00
Age 4 EF	.44	.17	.01
R-square			
Age 2 Tongue Task	.09	.06	.17
Age 2 Pig Bull	.17	.10	.10
Age 2 Ladybugs	.51	.15	.00
Age 2 Crayon Delay	.15	.08	.06
Age 4 DCCS	.46	.11	.00
Age 4 Digit Span	.13	.07	.06
Age 4 Yes/No	.05	.05	.32

Age 4 Gift Delay	.16	.07	.03
Age 4 BRIEF-P WM Scale	.04	.04	.34
Age 4 Pig/Bull	.18	.08	.02
Age 2 EF	.01	.02	.74
Age 4 EF	.56	.17	.00

Table 7

Standardized Parameter Estimates of the Bidirectional Longitudinal Pathways Between Age 2 EF, Age 4 EF, and Age 4 Social Skills and School Readiness

Parameter	Estimate	*SE*	*p*
Age 2 EF Factor Loadings			
Tongue Task	.35	.10	.00
Pig Bull	-.51	.11	.00
Ladybugs	.66	.10	.00
Crayon Delay	.38	.10	.00
Age 4 Social Skills on Age 2 EF	-.42	.23	.07
Age 4 Reading Ability on Age 2 EF	-.05	.19	.77
Age 4 Math Ability on Age 2 EF	.00	.18	.99
Age 4 EF Factor Loadings			
DCCS	.64	.07	.00
Digit Span	.42	.09	.00
Yes/No	.22	.10	.04
Gift Delay	.37	.08	.00
BRIEF-P WM Scale	.30	.09	.00
Pig/Bull	.47	.08	.00
Age 4 EF on Age 2 EF	.67	.12	.00
Age 4 Social Skills on Age 4 EF	.59	.22	.01
Age 4 Reading Ability on Age 4 EF	.34	.18	.07
Age 4 Math Ability on Age 4 EF	.49	.17	.00
Residual Variances			
Age 2 Tongue Task	.88	.07	.00
Age 2 Pig Bull	.74	.12	.00
Age 2 Ladybugs	.56	.13	.00
Age 2Crayon Delay	.86	.07	.00
Age 4 DCCS	.59	.09	.00
Age 4 Digit Span	.83	.07	.00
Age 4 Yes/No	.95	.04	.00
Age 4 Gift Delay	.86	.06	.00
Age 4 BRIEF-P WM Scale	.91	.05	.00
Age 4 Pig/Bull	.78	.08	.00
Age 4 Social Skills	.81	.12	.00
Age 4 Reading Ability	.91	.06	.00
Age 4 Math Ability	.76	.08	.00
Age 4 EF	.55	.16	.00
R-square			
Age 2 Tongue Task	.12	.07	.08
Age 2 Pig Bull	.26	.12	.03
Age 2 Ladybugs	.44	.13	.00
Age 2 Crayon Delay	.14	.07	.05
Age 4 DCCS	.41	.09	.00

Age 4 Digit Span	.17	.07	.02
Age 4 Yes/No	.05	.04	.30
Age 4 Gift Delay	.14	.06	.02
Age 4 BRIEF-P WM Scale	.09	.05	.09
Age 4 Pig/Bull	.22	.08	.00
Age 4 Social Skills	.19	.12	.11
Age 4 Reading Ability	.09	.06	.15
Age 4 Math Ability	.24	.08	.00
Age 4 EF	.45	.16	.00

Table 8

Standardized Parameter Estimates of the Bidirectional Longitudinal Pathways Between Infant Attention, EF, and Outcome Variables Controlling for Verbal Ability

Parameter	Estimate	*SE*	*p*
Age 2 EF Factor Loadings			
Tongue Task	.30	.11	.01
Pig Bull	-.44	.13	.00
Ladybugs	.70	.11	.00
Crayon Delay	.39	.10	.00
Age 2 EF on 5mo Longest Look	-.07	.12	.58
Age 2 EF on 5mo Novelty Score	.01	.11	.95
Age 2 EF on 5mo Orienting	.03	.11	.81
Age 4 Social Skills on Age 2 EF	-.41	.31	.19
Age 4 Reading Ability on Age 2 EF	-.25	.28	.37
Age 4 Math Ability on Age 2 EF	-.24	.28	.40
Age 4 EF Factor Loadings			
DCCS	.66	.08	.00
Digit Span	.40	.09	.00
Yes/No	.23	.10	.03
Gift Delay	.39	.08	.00
BRIEF-P WM Scale	.24	.10	.02
Pig/Bull	.41	.09	.00
Age 4 EF on Age 2 EF	.75	.12	.00
Age 4 EF on 5mo Longest Look	.01	.11	.95
Age 4 EF on 5mo Novelty Score	-.02	.11	.88
Age 4 EF on 5mo Orienting	-.04	.11	.68
Age 4 Social Skills on Age 4 EF	.56	.31	.07
Age 4 Reading Ability on Age 4 EF	.52	.27	.05
Age 4 Math Ability on Age 4 EF	.66	.27	.01
Residual Variances			
Age 2 Tongue Task	.92	.06	.00
Age 2 Pig Bull	.81	.11	.00
Age 2 Ladybugs	.52	.15	.00
Age 2 Crayon Delay	.85	.08	.00
Age 4 DCCS	.57	.10	.00
Age 4 Digit Span	.84	.07	.00
Age 4 Yes/No	.95	.05	.00
Age 4 Gift Delay	.85	.07	.00
Age 4 BRIEF-P WM Scale	.94	.04	.00
Age 4 Pig/Bull	.84	.05	.00
Age 4 Social Skills	.84	.13	.00
Age 4 Reading Ability	.84	.10	.00
Age 4 Math Ability	.72	.11	.00
Age 2 EF	.99	.02	.00

Age 4 EF	.44	.18	.01
R-square			
Age 2 Tongue Task	.07	.06	.22
Age 2 Pig Bull	.26	.12	.03
Age 2 Ladybugs	.36	.12	.00
Age 2 Crayon Delay	.18	.08	.03
Age 4 DCCS	.44	.08	.00
Age 4 Digit Span	.14	.06	.03
Age 4 Yes/No	.10	.06	.08
Age 4 Gift Delay	.09	.05	.08
Age 4 BRIEF-P WM Scale	.06	.04	.14
Age 4 Pig/Bull	.15	.06	.02
Age 4 Social Skills			
Age 4 Reading Ability			
Age 4 Math Ability			
Age 2 EF	.01	.03	.61
Age 4 EF	.60	.22	.01

Figure 1
Standardized Values for Unitary Model of Age 2 EF

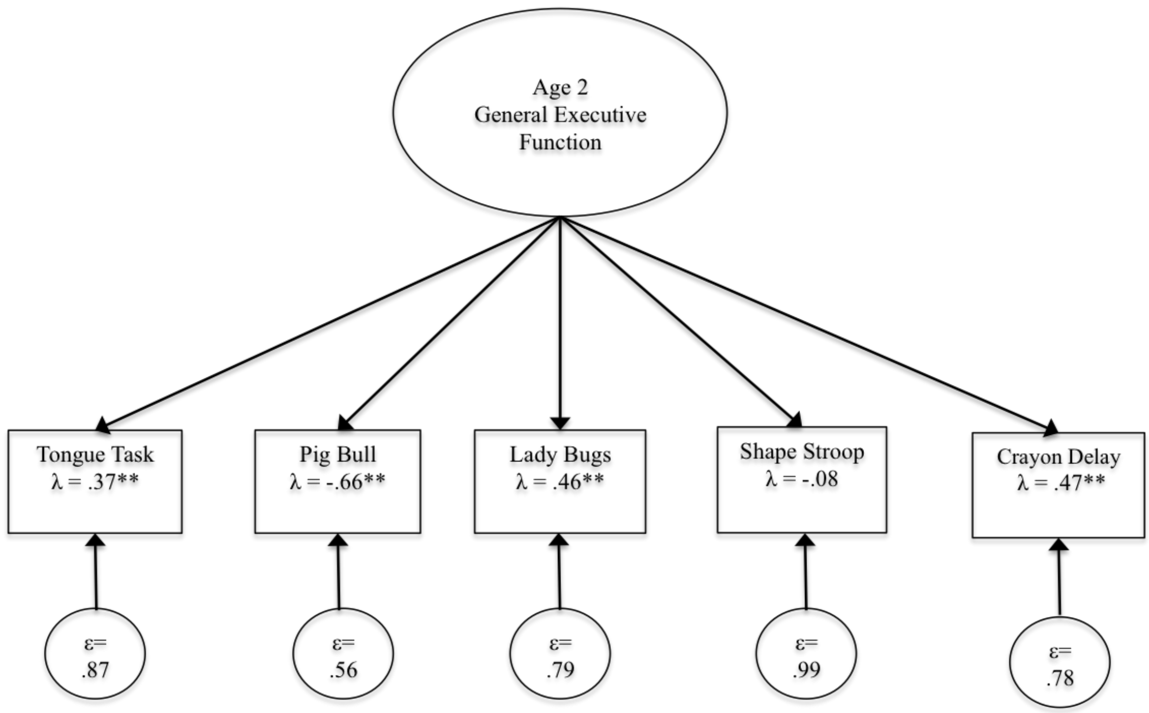


Figure 2

Proposed Bifactor Model of EF at Age 4. Latent Variables are Represented by Ovals, and Observed Variables by Rectangles

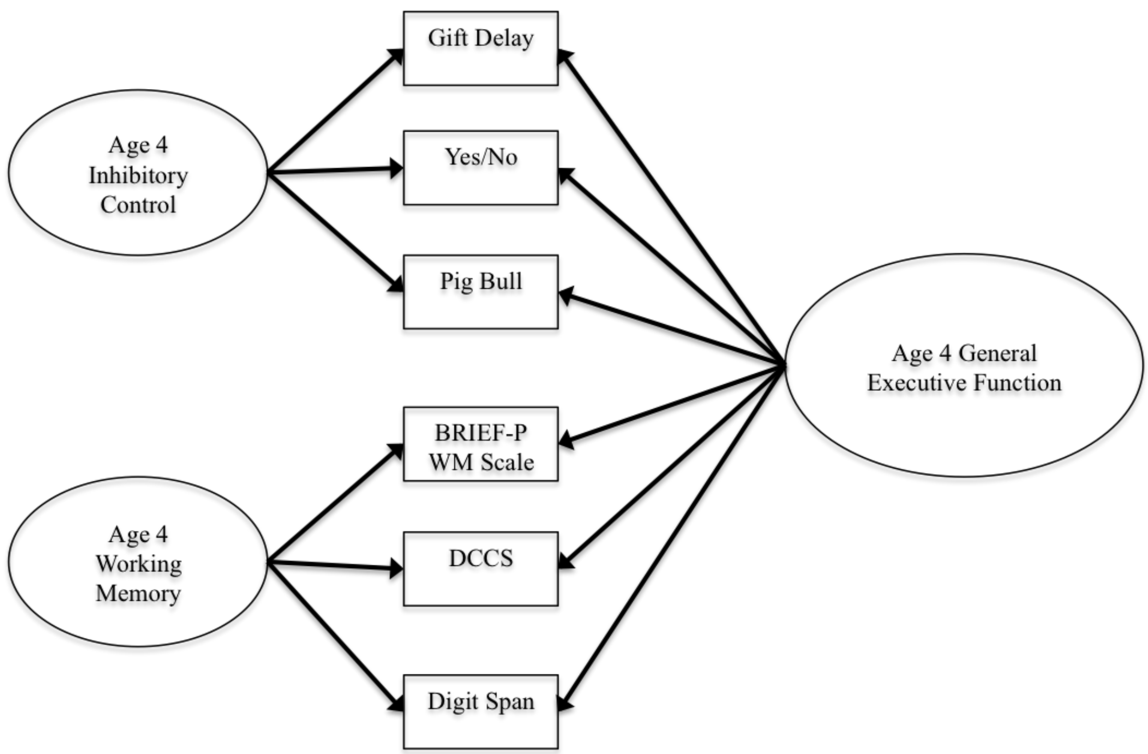


Figure 3
Proposed Second Order Model of EF at Age 4

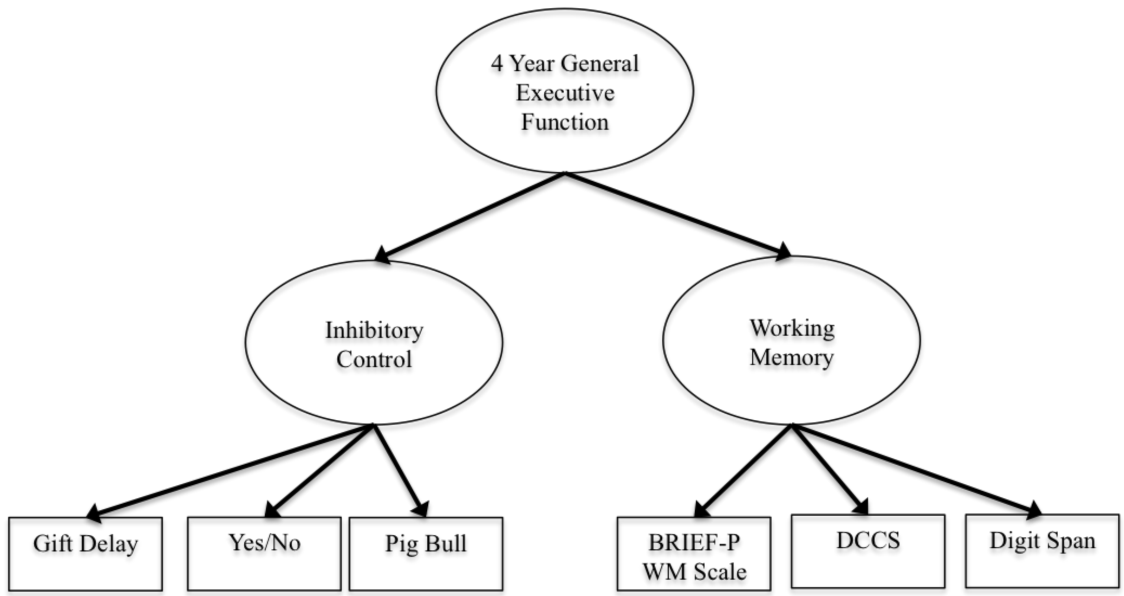
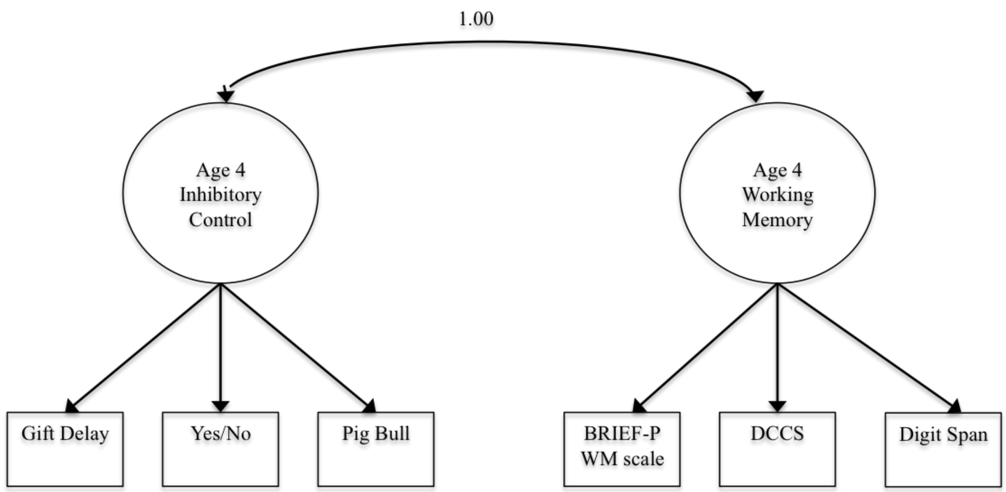
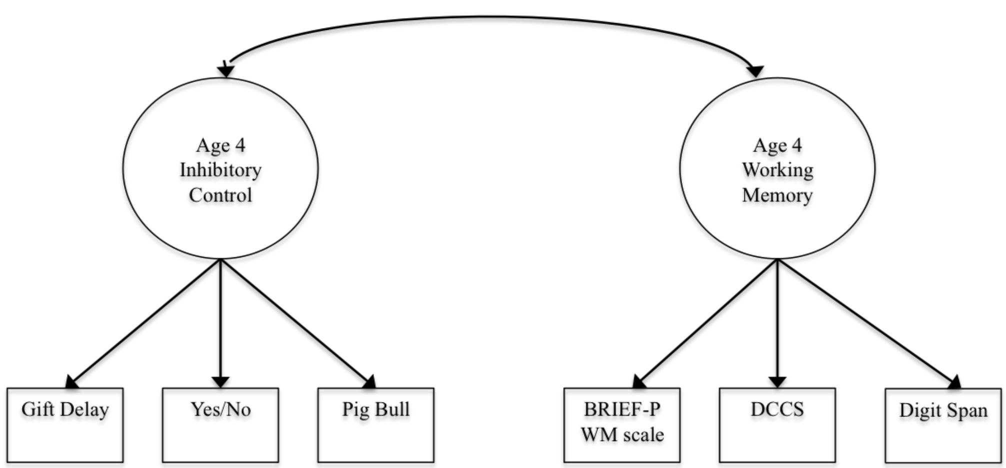


Figure 4

Proposed Nested Models of EF at Age 4



Model with the correlation between the latent variables fixed to 1.00



Model with the correlation between the latent variables freed to be estimated

Figure 5

Standardized Values for Unitary Model of Age 4 EF

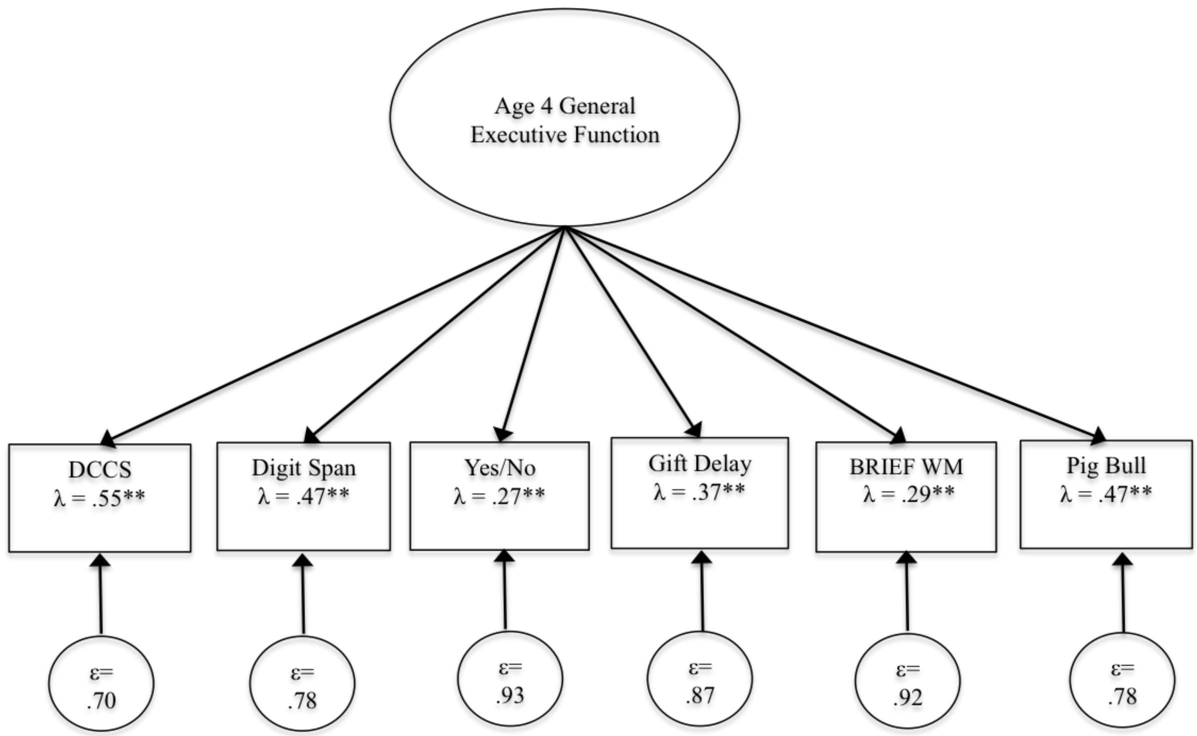
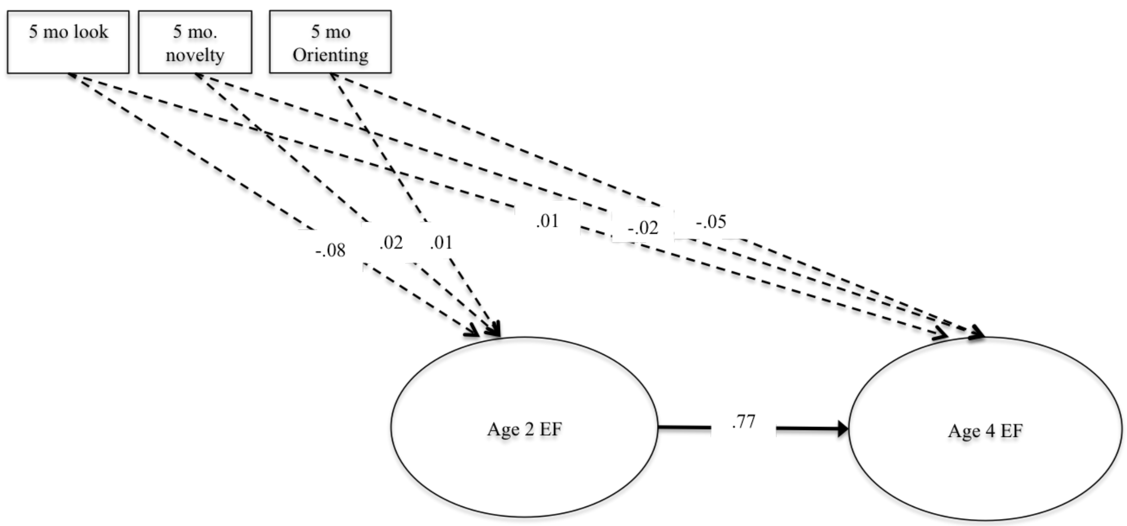


Figure 6

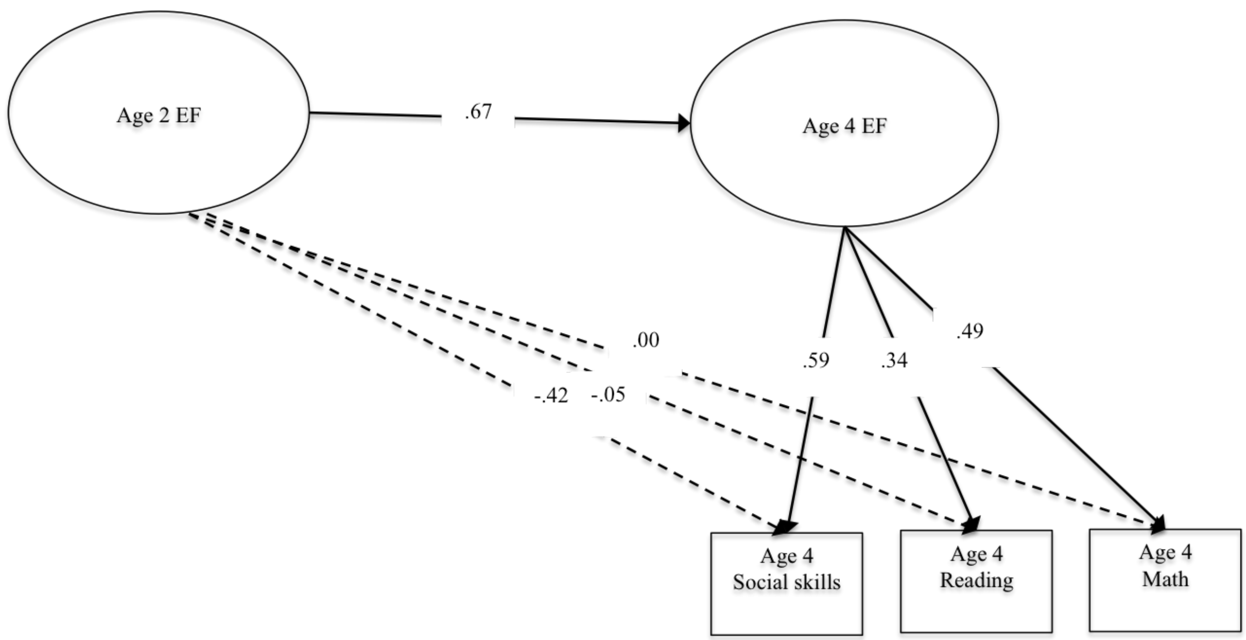
Structural Equation Model Showing the Relation between Infant Attention and Age 2 and Age 4 EF



Significant paths are indicated by solid lines ($p \leq .05$); nonsignificant ones are indicated by dashed lines ($p > .05$). Numbers on the solid and dashed lines represent factor loadings.

Figure 7

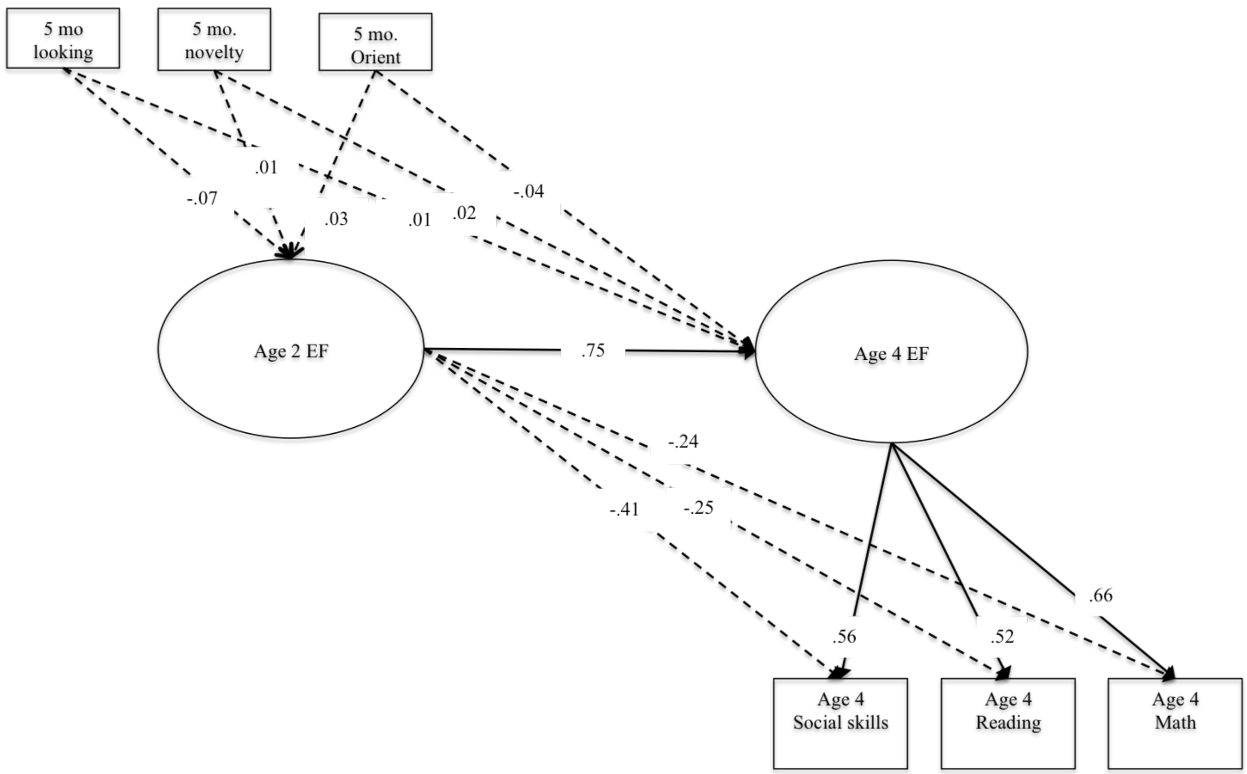
Structural Equation Model Showing the Relation between Age 2 and Age 4 EF, Social Skills, Reading Ability, and Math Ability



Significant paths are indicated by solid lines ($p \leq .05$); nonsignificant ones are indicated by dashed lines ($p > .05$). Numbers on the solid and dashed lines represent factor loadings.

Figure 8

Structural Equation Model Showing the Relation between Infant Attention, Age 2 and Age 4 EF, Verbal Ability, Social Skills, Reading Ability, and Math Ability



Significant paths are indicated by solid lines ($p \leq .05$); nonsignificant ones are indicated by dashed lines ($p > .05$). Numbers on the solid and dashed lines represent factor loadings.