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Verbal and nonverbal predictors of executive function in early childhood

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Abstract

The study of executive function (EF) has become increasingly popular in multiple areas of research. A wealth of evidence has supported the value of EF in shaping notable outcomes across typical and atypical development; however, little evidence has supported the cognitive contributors to early EF development. The current study used data from a large longitudinal sample of healthy children to investigate the differential influence of verbal and nonverbal cognition on later EF. Participants were assessed at 2 years of age using the Mullen Scales of Early Learning, and Mullen scores were used to calculate nonverbal and verbal developmental quotients. Executive function was measured at 6 years using assessments from the Stanford-Binet, Cambridge Neuropsychological Test Automated Battery, and the Behavior Rating Inventory of Executive Function. Results suggested that early nonverbal cognition was a better predictor of 6-year EF as measured by task-based laboratory assessments, whereas verbal cognition was a better predictor of parent-reported EF. Findings are discussed in regard to EF development and characteristics of EF measurement.

Executive function (EF) is a significant predictor of academic achievement (Diamond & Lee, 2011; Jacob & Parkinson, 2015; Willoughby, Magnus, Vernon-Feagans, & Blair, 2016) and is strongly related to a range of other real-world outcomes (Moffitt et al., 2011). Deficits in EF are associated with a variety of neurodevelopmental and psychiatric disorders (Bishop, 1993; Goldberg et al., 2005; Hooper et al., 2008; Hovik et al., 2017; Just, Cherkassky, Keller, Kana, & Minshew, 2007; Lewin et al., 2014; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). As a result of these outcomes, the study of EF has grown increasingly popular across multiple areas of research. Although substantial research has measured

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predictors and correlates of EF from early childhood (e.g., Cuevas & Bell, 2013) through adolescence (Sigman, Cohen, & Beckwith, 1997), the predictors associated with EF development have yet to be fully illuminated. In the current study, we explored the predictive value of toddler cognition on EF performance in early childhood to determine which class of behaviors, nonverbal or verbal, more strongly predicted EF.

Executive function has been operationalized in a number of ways throughout the literature, including as goal-directed behaviors that allow an individual to override automatic responses (Garon, Bryson, & Smith, 2008), control processes that regulate thoughts and actions (Miyake & Friedman, 2012), and self-regulatory mental processes (Wiebe et al., 2011). Although the specific definitions of EF vary, the consensus is that it represents the higher-order cognitive processing that is controlled by prefrontal areas of the brain (Diamond, 2002; Kane & Engle, 2002). Behaviors reflective of EF are thought to be regulated by a broader neural network that is also responsible for inhibiting automatic responses and efficiently executing goal-directed behaviors (E. K. Miller & Cohen, 2001).

A well-known theoretical framework of EF divides the construct into three factors: working memory, response inhibition, and set shifting (Miyake et al., 2000). This three-factor structure has been supported in both older children and adults (Fisk & Sharp, 2004; Friedman et al., 2008; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003), and the framework has been applied to young children as well (Garon et al., 2008; Müller, Liebermann-Finestone, Carpendale, Hammond, & Bibok, 2012). However, during early childhood when EF is first emerging, its structure may differ; for example, it may be a single executive control factor that later differentiates into multiple domains (Wiebe, Espy, & Charak, 2008; Wiebe et al., 2011). Other theories recognize the involvement of emotional or affective regulation in addition to cognition (Zelazo & Müller, 2002), or they approach EF as a set of problem-solving behaviors (Zelazo, Carter, Reznick, & Frye, 1997).

Despite the varying perspectives on the structure of EF in early childhood, there is agreement that this developmental period is critical for the emergence of EF and the implications for relations between EF and a variety of long-term cognitive, social, and emotional outcomes (e.g., Anderson, Anderson, Jacobs, & Smith, 2008; Carlson, 2005; Diamond & Lee, 2011; Garon et al., 2008). Researchers have examined EF across early childhood, the school years, and into adulthood; however, the processes underlying the emergence of EF and its early cognitive and behavioral correlates have been less well defined. One particular reason for this knowledge gap is the difficulty of measuring behaviors reflective of cognitive function in infants and toddlers.

The limited work that has been done concerning early nonverbal predictors of EF has largely revolved around attentional behaviors in infancy. Cognition during infancy has been commonly assessed through attention, one of the earliest-emerging cognitive abilities that can be reliably measured from an early age. Prior to the onset of mature language, attention-based paradigms have often been used to measure behaviors reflective of cognitive abilities, such as memory, processing speed, and categorization. Many techniques for studying cognition, sensation, and perception involve measures of looking time, or how long an infant fixates on a particular stimulus. According to information-processing theory, decreases in looking time are attributed to improved efficiency of the perceptual system, as more mature infants required less time to scan and process stimuli compared with less mature infants (Colombo, 2001, 2002; Colombo & Mitchell, 1990). Measures of cognitive efficiency in infancy based on look duration have been tied to later cognitive abilities such as intelligence, language, and memory (Colombo, Mitchell, Coldren, & Freeseman, 1991; Freeseman, Colombo, & Coldren, 1993; Jankowski & Rose, 1997; Rose & Feldman, 1997). Still, although there has been substantial research on attentional behaviors in relation to cognitive outcomes, very little research has explored precursors of EF performance specifically.

One of the prominent theoretical frameworks of early cognition is the attention network model (Posner & Petersen, 1990; Posner & Rothbart, 2007), which suggests that attention is a key behavior in the development of most higher-order cognitive abilities. This model emphasizes the value of attention especially regarding its ability to be studied across many different areas of research, from psychology to neuroscience. This theory describes the development of three distinct but related systems in the brain that are responsible for specific attentional behaviors: The alerting network allows for early sensitivity to incoming stimuli. The orienting network is responsible for selective attention as well as attention shifting, a key ability in the development of voluntary control of attention. The executive attention network comes online last and shows protracted development through middle childhood. It is responsible for sustained attention and higher-order cognitive abilities including EF. Given the strong links between attention and EF proposed by the attention network model, we expected to see similar relations between early nonverbal behaviors (especially those related to attention) and early childhood EF.

Strong evidence supports relations between the rapid development of language skills in toddlerhood and early childhood and later EF; however, limited research has examined how early verbal abilities compare to nonverbal cognition in predicting EF. Prominent figures in developmental research established the value of language for developing symbolic thought and self-regulation decades ago (Barkley, 2001; Vygotsky & Kozulin, 1986). For example, researchers have long theorized about the importance of private or self-directed speech in toddlers and preschoolers for the development of higher-order regulatory and cognitive abilities that are directly related to EF (Fernyhough & Fradley, 2005; Lidstone, Meins, & Fernyhough, 2010; Vygotsky, 1987). Additional developmental theory suggests the role of language in the development of intention or action control (Luria, 1969; Zelazo & Jacques, 1996). According to this framework, very young children initiate and regulate actions through verbal instructions from adults. As children age, they are gradually able to produce their own verbal commands to increasingly regulate behaviors. Research on children’s labeling and word use has suggested that early language plays a strong role in the development of control-related behaviors, such as conflict control (Müller, Zelazo, Hood, Leone, & Rohrer, 2004), task switching (Kirkham, Cruess, & Diamond, 2003; Kray, Eber, & Karbach, 2008), and inhibitory control (Kray, Kipp, & Karbach, 2009). All of this research suggests that language in infancy and toddlerhood plays a role in the emergence and development of EF in early childhood, but we have limited information regarding the predictive value of early verbal behaviors relative to nonverbal behaviors.

Existing research comparing verbal and nonverbal influences on EF in atypical populations (i.e., autism, Down syndrome, Williams syndrome) suggests that verbal abilities are more closely tied to concurrent EF in later stages of development (e.g., older childhood through adulthood; Campbell et al., 2013; Landry & Al-Taie, 2016; Landry, Russo, Dawkins, Zelazo, & Burack, 2012). The populations in these studies, however, have often been characterized as having notable language delays or difficulties in addition to EF deficits, so it is unclear whether or not these findings extend to younger typically developing samples. This area of research, although it has provided strong evidence for correlations between verbal abilities and EF, is cross-sectional and therefore unable to address questions of prediction. The current study expanded on this line of research by examining the longitudinal precursors to EF in a typically developing sample.

Developmental research has established links between broad cognitive abilities during infancy and toddlerhood and the emergence of EF in early childhood. Although the established relations between early cognition and later EF helped to grasp the range of EF precursors, we lack an understanding of which early behaviors are more strongly associated with EF outcomes in early childhood. The current study compared verbal and nonverbal predictors of EF using data from a large ongoing study of early development. This unique longitudinal sample included children who were tested multiple times during infancy, toddlerhood, and early childhood on widely used standardized measures of cognition. Additionally, using an assessment such as the Mullen Scales of Early Learning (Mullen, 1995) complemented findings from research on infant attention and cognitive efficiency and allowed for increased confidence in the validity of the results. We calculated verbal and nonverbal developmental quotient (DQ) scores from the Mullen scales at 2 years and analyzed them in relation to performance on a range of EF measures at 6 years. Complementary information provided from both parent-report and task-based measures allowed us to analyze information about children's behaviors as they commonly occurred within the home or family context (via a standardized parent-report measure of EF) and on a number of assessments conducted in a structured laboratory setting. The outcomes of these measures reflect critical components of EF, such as memory and planning. Based on previous research linking early cognition and EF, we expected that both verbal and nonverbal behaviors would predict EF but that nonverbal behaviors would have a stronger relation given the previous research linking attention with later cognition.

Method

Participants

This study was a secondary data analysis of a large corpus of longitudinal data obtained through a large ongoing project looking at behavior and brain development from birth through early adolescence that included community-based subsamples of single-born children (Knickmeyer et al., 2008) and twin pairs (Gilmore et al., 2010). Parents were initially recruited during pregnancy, and offspring were studied after birth. In the current study, participants' data were excluded for familial risk for serious mental illness, very preterm birth (before 32 weeks gestation), neonatal intensive care unit stay of longer than 24 hr, or any reported major medical event or diagnosis after birth. The main focus of the analyses was on the relation between Mullen scores at 2 years and EF at 6 years.[1] The final sample of children with data at both 2 years and 6 years included 227 children. Of these, 47.6% were male, and 104 were twins (see Table 1 for demographic data). Specific *N*s for analyses varied because of missing data across covariates or invalid or missing data for individual assessments or subscales.

Behavioral measures

All the tasks administered in this study were developmentally appropriate, widely used measures with high levels of validity and reliability across large ranges of developmental ability.

Mullen Scales of Early Learning (Mullen, 1995)—The Mullen scales are a well-regarded measure of general cognitive functioning and can be used with children from birth through 5 years of age. This measure was administered when children were 2 years old. The Mullen scales include five separate scales across the following domains: Gross Motor (GM), Fine Motor (FM), Visual Reception (VR), Receptive Language (RL), and Expressive Language (EL). Age-normed *T* scores of these outcomes (with the exception of GM) combine to generate an Early Learning Composite (ELC). Although the ELC is the most commonly used score in the Mullen scales, researchers have explored data by breaking it down into verbal and nonverbal components (DiStefano et al., 2016; Short et al., 2013; Wetherby et al., 2004). Developmental quotients are calculated by averaging the age equivalent (AE) scores of the components, dividing by chronological age, and multiplying by 100 (see Equations [1]). The nonverbal DQ (NVDQ) includes scales of VR and FM abilities, whereas the verbal DQ (VDQ) includes EL and RL. The GM Scale is not included in either DQ.

$$\mathrm{NVDQ} = \frac{\mathrm{average(of\ VR_{ae}\ and\ FM_{ae})}}{\mathrm{chronological\ age\ (months)}} * 100 \quad \mathrm{VDQ} = \frac{\mathrm{average(of\ RL_{ae}\ and\ EL_{ae})}}{\mathrm{chronological\ age\ (months)}} * 100 \qquad (1)$$

These scores allow for analyzing respective contributions of early verbal and nonverbal abilities at a more nuanced level than the ELC by itself. Though the primary focus of this study was on the NVDQ and VDQ scores, we also examined the predictive value of the ELC score on 6-year EF. Additionally, we considered the four Mullen scales that comprise NVDQ (VR and FM) and VDQ (RL and EL) to determine if one individual scale was driving patterns of results.

Stanford-Binet Intelligence Scales-Fifth Edition (Roid, 2003)—The Stanford-Binet Intelligence Scales are a standardized set of assessments widely used to assess IQ across the life span. The Stanford-Binet Intelligence Scales test cognitive abilities across five major domains. In the current study, the Working Memory factor index score was used to represent

[1]Data were also collected when children were 1 year of age. Previous research from our group suggested that 2-year scores are much more predictive of later behavior than are 1-year scores (Girault, 2017). We conducted exploratory analyses using the 1-year data to predict 6-year EF, and patterns were consistent with this earlier work.

EF abilities and the Abbreviated IQ (ABIQ) score was used as a measure of general intelligence. Both of these assessments were conducted at 6 years.

Working Memory: The Working Memory tests of the Stanford-Binet Intelligence Scales measure the ability to store, transform, and retrieve information from short-term memory stores (Roid, 2003). The Stanford-Binet Intelligence Scales include tests of verbal ("last word" and "memory for sentences") and nonverbal ("delayed response" and "block span") working memory and require participants to recall words/sentences or sequences of block taps. Working memory is widely considered one of the key components of EF from preschool age through adulthood (Garon et al., 2008; Miyake et al., 2000), and it has been repeatedly linked to learning and academic achievement (Jacob & Parkinson, 2015). This Stanford-Binet scale has been previously utilized as a measure of working memory as an aspect of EF (Skogan et al., 2014). Both parts of the Working Memory factor scale were not included with the earlier 6-year assessments, so the number of participants with this factor is much smaller than the number for the other measures (see Table 2 for specific *N*s).

Abbreviated IQ: In this study, the 6-year ABIQ score was used in the models to determine if the predictive relation between 2-year cognition and 6-year EF existed above and beyond general intelligence. In the Stanford-Binet Intelligence Scales, ABIQ is calculated from two subscales: Nonverbal Fluid Reasoning and Verbal Knowledge.

Cambridge Neuropsychological Test Automated Battery (Cambridge Cognition Ltd., 2006)—The Cambridge Neuropsychological Test Automated Battery (CANTAB) is a commonly used tool to measure cognitive function as it relates to underlying neurological networks. It includes tests designed to assess many aspects of cognition, with a number of tasks specifically targeting EF. Two specific tasks from the CANTAB were administered when children were 6 years of age and were analyzed as outcome variables for this analysis: Spatial Span (SSP) and Stockings of Cambridge (SOC). Tasks from the CANTAB have been used extensively as measures of EF across typical and atypical samples of young children (Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009; Henry & Bettenay, 2010; Luciana & Nelson, 1998). Because the range of scores in both of these CANTAB tests is much smaller than those in the other outcomes, scores were standardized for analyses using the mean and standard deviation of this sample of children.

Spatial Span: Spatial Span is a computerized version of the Corsi Block Tapping Test (Milner, 1971), a widely used measure of working memory. Although many of the CANTAB tasks assess working memory, our research team selected this particular task because the simplicity of instructions makes it more appropriate for 6-year-old children. Spatial Span requires participants to remember visuospatial patterns of increasing length. Participants are given three tries at each span length, and when all three attempts are incorrect, that test ends. The outcome variable used in the current study was the highest span length successfully completed (range = 2–9).

Stockings of Cambridge: Stockings of Cambridge is a computerized version of the Tower of London (Shallice, 1982). It is primarily a measure of planning, as participants are presented with sets of problems that require two to five moves to complete. Additionally, completion requires the use of working memory, as success depends on participants' ability to not only plan out a sequence of moves but to also remember that sequence and apply it to the problem. The outcome variable from SOC is the number of problems solved in the minimum number of moves (range = 0–18).

Behavior Rating Inventory of Executive Function (Gioia, Isquith, Guy, & Kenworthy, 2000)—The Behavior Rating Inventory of Executive Function (BRIEF) is a parent-report survey of behaviors related to EF, and parents completed this survey when children were 6 years of age. We included the BRIEF as an outcome in this study because it reflects parent ratings of EF across a variety of contexts (e.g., home, school, and social environments) and therefore may provide a different look at EF abilities. This measure is typically used by parents of children aged 5 to 18 years, and scores indicate severity of EF deficits, so that higher scores represent greater reported difficulty. The BRIEF generates eight clinical scales across two primary indices, and a Global Executive Composite (GEC) score is generated by adding the scores from all eight scales. All outcomes are gender- and age-normed, and the BRIEF scales show high internal consistency (α = .80–.98) and test–retest reliability (r = .81). Only the GEC was used in the current study to provide a broad measure of EF and to limit the number of analyses. Based on previous research regarding early cognition and later EF and the directionality of BRIEF scores, we expected to see a negative relation between Mullen scale performance and the BRIEF GEC.

Analysis plan

As a first step, bivariate correlations were estimated with generalized estimating equations (GEE) using methods from Yan and Fine (2004). All outcomes were standardized, and a GEE was fit for each pair of outcomes using only an indicator for type of test as a covariate. The correlation matrix was defined to account for correlations between siblings and twins as well as between the two tests for the same child. The estimates for the correlation between the tests for the same child are reported, and p values were calculated using a z test based on the standard error of the estimated covariances from the GEE model.

Next, the relation between Mullen scale scores and measures of EF at 6 years was estimated using GEE (Liang & Zeger, 1986; Yan & Fine, 2004), with each family (twins and/or twin or singleton siblings) treated as a cluster. Additionally, the ABIQ from the Stanford-Binet Intelligence Scales was included as a covariate to establish if predictive relations were specific to EF as opposed to general cognition. In each of the models, variable selection was performed using quasi-Akaike's information criterion (QIC; Pan, 2001) to select the best subset of potential covariates from gender, paternal education, gestational age at birth, and gestation number. Age at testing was not included because it was included in the calculation of the NVDQ and VDQ. The number of months since study inception was included to account for any sample drift or variation in task administration due to personnel turnover or historical change. Maternal education was initially included but later discarded because of its high correlation with paternal education, which had a stronger model fit. The first set of analyses was run with the Mullen ELC (T score) to establish general predictive relations. Next, we fit GEE models to see how predictive NVDQ and VDQ were of EF performance at 6 years. In addition to models including both DQ scores, separate models were fit and included only NVDQ or VDQ because of potential collinearity. The correlations between DQ scores and ABIQ indicated an additional potential issue with multicollinearity that could lead to inflated standard errors. However, because the coefficients for the effect of NVDQ and VDQ on the 6-year outcomes of interest were still significant even with potentially inflated standard errors, we are confident with our findings. In addition, models that did not include ABIQ had similar results for the effect of NVDQ and VDQ on the 6-year outcomes. Primary analyses focused on NVDQ and VDQ scores generated from 2-year Mullen scale data. Further, we analyzed the four separate Mullen scales that comprise the NVDQ and VDQ scores (NVDQ = VR and FM; VDQ = RL and EL) to establish whether any of the individual scales were driving significant DQ results. These scale analyses used raw scores and controlled for age at testing.

To determine which of the Mullen DQ scores were more predictive of 6-year outcomes, we utilized QIC to assess model fit (Pan, 2001). When examining multiple models, the model with the lower QIC value was preferred. A lower QIC indicates a better model fit and that the variables included in the model better predict the outcome.

The makeup of our sample allowed for sensitivity analyses to determine the strength of effects across different subsamples. Here, we divided our sample into single-born children and twins and used the same analytical strategies described previously. These analyses aimed to confirm the reliability of results across samples with potentially different developmental patterns. Additionally, because twins were overrepresented in our sample, this analysis was important to ensure that results are not driven by the high number of twins in our sample and can therefore be generalized to a wider population.

Results

Descriptive statistics

Mean scores for all measures and sample sizes for GEE models are reported in Table 2. Mean scores on the 6-year EF assessments included all participants for whom we had valid data at the 2-year assessment and for at least one 6-year measure. Although the mean values for the Stanford-Binet Working Memory factor scale were slightly higher than the expected population mean (100), the standard deviations were in line with normative data (Table 2). Distributions were examined for outliers (greater than three standard deviations from the mean). The CANTAB SSP task had two outliers (scores of 0, meaning that participants were unable to complete even the first sequence); however, all the main conclusions with this outcome were the same when outliers were removed. Therefore, all scores were included for all analyses.

Bivariate correlations revealed significant associations between the 2-year NVDQ and VDQ scores and 6-year task-based assessments (Stanford-Binet Working Memory factor scale and both CANTAB tasks). Significant correlations between Mullen DQ scores and the BRIEF GEC were negative, because the BRIEF is scored such that higher scores indicate more EF deficits (Table 3).

Mullen Early Learning Composite

Initial analyses predicted 6-year EF performance from the Mullen ELC using GEE modeling, including all covariates described earlier and controlling for the 6-year ABIQ. The ELC at 2 years significantly predicted each of the 6-year outcome measures (Table 4). These results support a relation between early cognition at 2 years and later EF. For the next series of analyses, we further examined the relative predictive value of 2-year NVDQ and VDQ scores on 6-year EF.

Nonverbal and verbal developmental quotients

When modeled individually, both NVDQ and VDQ scores significantly predicted performance on the Stanford-Binet Working Memory factor scale and on the CANTAB SSP task. Only VDQ significantly predicted the BRIEF GEC (Table 5). To further explore the predictive nature of the NVDQ and VDQ on 6-year EF, both scores were entered into the same model. In combined models, the NVDQ significantly predicted SSP while the VDQ predicted the BRIEF GEC (Table 6). Additionally, the effect of the NVDQ on the Stanford-Binet Working Memory factor scale was marginally significant ($p = .055$).

Although the GEE results highlighted variables that were statistically significant predictors of EF, we used QIC to determine relative model strength by comparing models with the NVDQ as a predictor to those with the VDQ as a predictor. Quasi-Akaike's information criterion results suggested that the NVDQ had a better model fit for both the Stanford-Binet Working Memory factor scale and for both CANTAB outcomes (SSP and SOC), while the VDQ had a better fit predicting the BRIEF GEC.

Individual Mullen scales

We then further probed the predictive value of 2-year NVDQ and VDQ scores by including all four cognitive scales (raw scores) in the GEE models. Based on the patterns established by the NVDQ and VDQ models, we expected differential relations across these scales but were interested to see if the specific components of DQ scores carried different weights. Using QIC to determine which of the scales to include in each model and controlling for the 6-year ABIQ, we established that models with significant predictive value of the NVDQ were largely driven by VR: This Scale significantly predicted the Stanford-Binet Working Memory factor scale and both CANTAB tasks. The significant relation between the VDQ and BRIEF GEC was driven by the RL Scale (Table 7). It should be noted that the coefficients in these results should not be directly compared to those from the models using the NVDQ and VDQ, because the range of raw scores differed greatly from that of DQ scores.

Sensitivity analysis

The composition of our sample allowed us to analyze subgroups (i.e., single-born children and twins) to establish the reliability of findings from DQ scores. This analysis was particularly important given the oversampling of twins (as a result of the study design). Patterns were largely similar between groups; however, the twin sample showed slightly stronger relations between the VDQ and Stanford-Binet Working Memory factor scale, and it showed a weaker relation between the VDQ and BRIEF GEC (Supplemental Table 1). The difference in the coefficients for twins and singletons was not significant for any measure of 2-year cognition predicting any measure of 6-year EF. In particular, those relationships that were found to be significant in the full sample (the NVDQ predicting the Stanford-Binet Working Memory factor scale and SSP as well as the VDQ predicting the BRIEF GEC) did not have a large difference in coefficient size for the twin and singleton samples. This result indicated that these relationships are not dependent on twin status. These variations were likely partially due to the effects of dividing the sample, resulting in a loss of power, and none of the differences were statistically significant.

Discussion

The current study explored the relative predictive value of early verbal and nonverbal behaviors for EF performance in childhood. When predictor variables were included independently, we found significant effects of both the NVDQ and VDQ on the Stanford-Binet Working Memory factor scale, which makes sense as this factor included verbal and nonverbal items. Independently, only the NVDQ significantly predicted the SSP, a highly visuospatial task, and only the VDQ significantly predicted the BRIEF GEC. When both predictors were included in the same model, we saw a suppression of effects, likely due to high levels of collinearity between predictors. In these models, the NVDQ by itself significantly predicted the SSP, and the relation with the Stanford-Binet Working Memory factor scale was marginally significant. The VDQ by itself significantly predicted the BRIEF GEC. Quasi-Akaike’s information criterion analyses revealed a better model fit for the NVDQ in predicting performance on task-based measures of EF (Stanford-Binet Working Memory, SSP, and SOC) and a better fit for the VDQ in predicting the BRIEF GEC.

Models examining the effect of individual Mullen scales on 6-year EF suggested that specific scales may be driving these results. The NVDQ score was composed of the VR and FM Scales, although the VR Scale was selected in all models except for the BRIEF and the FM Scale was selected only for the SSP (though it was not statistically significant in this model). The VR Scale significantly predicted performance on the Stanford-Binet Working Memory factor scale, SSP, and SOC. Although fine motor behaviors are more closely tied to cognition in the early stages of development than they are later (Berger, 2010; Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010; Yu & Smith, 2017), it was unsurprising that performance on the VR Scale was a better predictor of later EF. Many of the VR Scale items reflect aspects of attention, such as visual discrimination or memory, and attentional behaviors have repeatedly been tied to EF; therefore, these results are consistent with previous findings regarding early cognitive abilities and later EF (Cuevas & Bell, 2013; Rose, Feldman, & Jankowski, 2012).

Our results suggest that the early nonverbal aspects of cognition are better predictors of task-based EF performance. The significant relations between the NVDQ, especially VR, and 6-year laboratory-based measures of EF support the attention network model (Posner & Petersen, 1990). According to this theory, the mechanisms related to early attention behaviors are directly related to and support the development of later-emerging EF abilities. Our results are consistent with this developmental pattern: The VR Scale significantly predicted all three laboratory-based outcomes (Stanford-Binet Working Memory factor scale and both CANTAB tasks), which measure EF in the form of working-memory and planning abilities.

In contrast to laboratory-based EF, parent-reported EF as measured by the BRIEF was significantly predicted by early verbal abilities. Some of the scales on the BRIEF are more closely tied to self-regulation and emotion regulation (e.g., the three scales that comprise the Behavior Regulation Index). This specific finding supports theories of the importance of early language abilities for EF and self-regulatory development. Children with more advanced language abilities may be able to better initiate and regulate their behaviors (Vallaton & Ayoub, 2011; Zelazo & Jacques, 1996) and may therefore perform better at tasks requiring conflict or inhibitory control (Kray et al., 2009; Müller et al., 2004). Alternatively, the association between early verbal abilities and later EF as measured by parent report may be related to the established links between early social interaction and EF in childhood (Bernier, Carlson, Deschênes, & Matte-Gagné, 2012; Hammond, Müller, Carpendale, Bibok, & Liebermann-Finestone, 2012; Hughes & Ensor, 2009). This significant prediction may highlight the value of verbal cognition, as it stems from early social relationships, for the emergence of EF.

The VDQ score was composed of the two language scales: RL and EL. The RL Scale was identified only for the BRIEF, and the EL Scale was not selected in any of the models. These patterns may reflect the fact that language abilities vary drastically at 2 years, and the RL Scale may be easier for parents to report and for researchers to measure. Whereas the EL Scale may be easier for parents and researchers to directly observe, it is likely more difficult to elicit and measure accurately in a new setting due to children’s differences in temperament, tiredness, wariness of new places or people, and the like.

Unlike the laboratory-based assessments (the Stanford-Binet Intelligence Scales and CANTAB), the BRIEF is able to obtain information about children’s behaviors across a variety of contexts. From this perspective, the GEC score generated from the BRIEF may be a better indicator of children’s broad EF abilities or of wide-ranging EF deficits compared with scores from a single laboratory visit (McAuley, Chen, Goos, Schachar, & Crosbie, 2010). Research has shown limited agreement between children’s scores on EF tasks and parent-reported behaviors (Anderson, Anderson, Jacobs, Northam, & Michiewicz, 2002; McAuley et al., 2010; Vriezen & Pigott, 2002). Our sample showed a similar pattern: Correlations between scores on task-based assessments and the BRIEF GEC were relatively weak. These discrepancies may help to explain why the predictive value of nonverbal cognition did not extend to parent-reported EF as measured by the BRIEF.

Additionally, nonverbal measures of cognition during toddlerhood may be a more stable indicator of cognitive ability. At these early ages, language skills are developing very rapidly, and the predictive value of individual differences in these abilities is difficult to determine. This was especially true given that we used only one primary measure (the Mullen Scales of Early Learning), even if it did tap both receptive and expressive language. Although behaviors measured by the NVDQ scales were also subject to such variation, the effects may not have been as strong. Therefore, the VR Scale may be capturing more stable behaviors reflective of early cognition that provide the foundation for the development of

EF. Lastly, it is possible that the relation between the VDQ and BRIEF scores may reflect the type of measurement (i.e., parent report) as opposed to underlying cognitive development. Given the difficulty of measurement in infants and toddlers, language scores obtained with the Mullen scales (as well as with other standardized assessments) are often largely based on parent report, so they may reflect different degrees of accuracy. Although these strategies may also be employed in the nonverbal scales, the extent to which those scores depend on parent report is much lower.

The results of this study contrast with previous research looking at verbal and nonverbal influences of EF in atypical populations (Campbell et al., 2013; Landry et al., 2012). On one hand, this discrepancy raises interesting questions regarding differences in developmental patterns between typical and atypical populations. Additionally, one of the strengths of the current study was its longitudinal design, so previous cross-sectional studies that showed stronger relations between verbal cognition and EF have not allowed for prediction over time. Future research should directly compare verbal and nonverbal precursors of EF across different populations, as such research would likely have strong implications for early intervention research.

One of the main limitations of this study was the intentionally narrow inclusion criteria. To better interpret the results, we excluded a large percentage of our sample. Thus, the results likely extend only to healthy, typically developing children. Analysis of data from a more developmentally diverse sample (e.g., children born premature or diagnosed with neurodevelopmental disabilities) could possibly yield more generalizable results and provide information about cognitive relations over time for a broader range of developmental abilities. Additionally, the mean score on the Stanford-Binet Working Memory outcome was higher than reported population means. This finding could reflect the nature of our sample (i.e., the narrow inclusion criteria), or it could indicate effects of testers; however, we have largely corrected for these possible effects through statistical methods and the covariates included in our models. Lastly, many of the Mullen scores, especially those from language scales, were to some extent reflective of parent-reported behaviors, in addition to performance during laboratory testing. While this finding raises questions about precisely what these scales were measuring, given the typical difficulties associated with toddler assessment, parent contribution likely results in more accurate data collection.

Conclusions

This study explored the relative predictive value of verbal and nonverbal aspects of early cognition on performance on EF tasks in early childhood in a large, community-based longitudinal sample. Results suggested that nonverbal cognition is a better predictor of EF as it was measured by task-based assessments. Specifically, behaviors related to VR most strongly predicted performance on EF tasks and therefore supported attention-based theories of cognitive development. This study provided unique insight into developmental precursors of EF by directly comparing the predictive value of verbal and nonverbal behaviors in toddlerhood. Relations between early cognition and later EF should be explored further in more diverse samples and across wider age ranges (i.e., through middle childhood or early adolescence). Future research should also consider the long-range differential effects of verbal and nonverbal abilities on behaviors related to EF (e.g., academic achievement). Additionally, these findings suggest that when considering early interventions aimed at improving EF and subsequent academic achievement, it may be beneficial to target behaviors specifically within the nonverbal domain.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Sample demographics for participants included in models predicting 6-year outcomes from 2-year scores (*N* = 227).

Demographic	***N* (%)**
Gender (male)	108 (47.58)
Gestation (single-born)	123 (54.19)
Race (Caucasian) *	180 (79.30)
Ethnicity (Hispanic) *	10 (4.41)
	Mean (*SD*)
Gestational Age at Birth (weeks)	38.10 (1.92)
Age at Testing, 2-Year Mullen Scales of Early Learning (MSEL) (months)	24.60 (0.77)
Age at Testing, 6-Year Executive Function (months)	74.10 (1.84)
Maternal Education (years)	15.77 (2.98)
Paternal Education (years)	15.26 (3.38)
Household Income (thousands)	77.86 (53.73)

*Values refer to reported maternal race and ethnicity.

Table 2

Average scores on cognitive measures at 2 and 6 years.

Measure	Score Mean (*SD*)
2-Year Measures	
Mullen Scales of Early Learning	
Early Learning Composite	109.27 (15.33)
Nonverbal Developmental Quotient	101.83 (12.88)
Verbal Developmental Quotient	106.78 (15.32)
6-Year Measures	
Stanford-Binet Intelligence Scales	
Working Memory (N = 109)	112.07 (13.31)
Abbreviated IQ (N = 223)	106.22 (13.35)
CANTAB	
Spatial Span (N = 224)	3.73 (0.91)
Stockings of Cambridge (N = 230)	5.31 (1.87)
BRIEF	
Global Executive Composite (N = 224)	50.92 (9.79)

Note. *N*s represent the number of participants included in generalized estimating equations models predicting each outcome measure from the 2-year predictors. Sample sizes vary because of missing covariates, because of invalid data, or because a particular assessment was not completed. CANTAB = Cambridge Neuropsychological Test Automated Battery; BRIEF = Behavior Rating Inventory of Executive Function.

Table 3

Bivariate correlations among 2-year and 6-year cognitive assessments.

	NVDQ	VDQ	SB WM	SB ABIQ	SSP	SOC
NVDQ	—	—	—	—	—	—
VDQ	.67**	—	—	—	—	—
SB WM	.48**	.38**	—	—	—	—
SB ABIQ	.42**	.44**	.72**	—	—	—
SSP	.33**	.19**	.36**	.28**	—	—
SOC	.25**	.19**	.18*	.25**	.21**	—
BRIEF	−.14*	−.20**	−.18*	−.13	.04	−.13*

* $p < .05$.

** $p < .001$.

Note. NVDQ = Nonverbal Developmental Quotient; VDQ = Verbal Developmental Quotient; SB WM = Stanford-Binet Working Memory score; SB ABIQ = Stanford-Binet Abbreviated IQ score; SSP = Cambridge Neuropsychological Test Automated Battery Spatial Span; SOC = Cambridge Neuropsychological Test Automated Battery Stockings of Cambridge; BRIEF = Behavior Rating Inventory of Executive Function Global Executive Composite.

Table 4

Generalized estimating equations models predicting 6-year executive function from the Mullen Scales of Early Learning Composite (ELC) score, while controlling for 6-year Abbreviated IQ.

	ELC, 2-year ***β (SE)***
Stanford-Binet	
Working Memory	0.205 (.06)**
Cambridge Neuropsychological Test Automated Battery	
Spatial Span+	0.236 (.07)**
Stockings of Cambridge+	0.129 (.09)
Behavior Rating Inventory of Executive Function	
Global Executive Composite	−0.106 (.04)*

* $p < .05$.

** $p < .01$. + scores standardized.

Table 5

Generalized estimating equations models predicting 6-year outcomes from the VDQ and NVDQ at 2 years, with separate models controlling for 6-year Abbreviated IQ.

	Mullen NVDQ ***β (SE)***	**Mullen VDQ** ***β (SE)***
Stanford-Binet		
Working Memory	0.203 (.07)**	0.153 (.07)*
Cambridge Neuropsychological Test Automated Battery		
Spatial Span+	0.294 (0.07)**	0.118 (.08)
Stockings of Cambridge+	0.139 (.08)	0.093 (.10)
Behavior Rating Inventory of Executive Function		
Global Executive Composite	−0.078 (.06)	−0.126 (.04)**

* $p < .05$.

** $p < .01$. + scores standardized. *Note*. NVDQ = nonverbal developmental quotient; VDQ = verbal developmental quotient.

Table 6

Generalized estimating equations models predicting 6-year outcomes from VDQ and NVDQ at 2 years, with combined models controlling for 6-year Abbreviated IQ.

	Mullen NVDQ ***β(SE)***	**Mullen VDQ** ***β (SE)***
Stanford-Binet		
Working Memory	0.166 (.09)	0.060 (.08)
Cambridge Neuropsychological Test Automated Battery		
Spatial Span+	0.321 (.09)**	−0.051 (.09)
Stockings of Cambridge+	0.129 (.09)	0.017 (.10)
Behavior Rating Inventory of Executive Function		
Global Executive Composite	0.035 (.08)	−0.145 (.07)*

*$p < .05$.

**$p < .01$. + scores standardized. *Note*. NVDQ = nonverbal developmental quotient; VDQ = verbal developmental quotient.

Table 7

Generalized estimating equations models predicting 6-year executive function from 2-year MSEL Scales, while controlling for 6-year Abbreviated IQ.

	VR β (SE)	FM β (SE)	RL β (SE)	EL β (SE)
Stanford-Binet				
Working Memory	0.808 (.24)**	—	—	—
Cambridge Neuropsychological Test Automated Battery				
Spatial Span+	0.224 (.08)**	0.116 (.07)	—	—
Stockings of Cambridge+	0.185 (.08)*	—	—	—
Behavior Rating Inventory of Executive Function				
Global Executive Composite	—	—	−0.477 (.23)*	—

* $p < .05$.

** $p < .01$. + scores standardized. *Note*. MSEL = Mullen Scales of Early Learning; VR = Visual Reception; FM = Fine Motor; RL = Receptive Language; EL = Expressive Language.