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Executive Functioning and Behavior among Very Low Birth Weight Children at School-Age

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EXECUTIVE FUNCTIONING AND BEHAVIOR AMONG VERY LOW BIRTH WEIGHT CHILDREN AT SCHOOL-AGE

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ABSTRACT

Children born prematurely and/or with low birth weight (LBW) are at significantly higher risk than their full-term peers for developing cognitive, behavioral, attention, and executive functioning (EF) difficulties by school-age. The difficulties experienced by this population typically persist well into adolescence and vary as a function of birth weight, with infants weighing less at significantly higher risk for long-term problems. However, there is little consensus with regard to the specific factors that place preterm and LBW children at greatest risk for EF and behavioral impairments. A primary purpose of the current study was to examine the degree to which neonatal/ medical and social/environmental variables influence very low birth weight (VLBW) children's EF and behavioral abilities at school-age. Results indicated that (1) length of time on mechanical ventilation in the neonatal period was related to children's mental flexibility, (2) maternal marital status was related to children's hyperactive/impulsive behavior, and (3) SES was related to children's physical symptoms at school-age.

A secondary purpose of the current study was to explore the degree to which performance-based (objective) and parent rating (subjective) measures of EF are related to one another. Research has shown that objective and subjective measures of EF and behavior often yield different results and lack significant intercorrelations. However, the majority of research examining the relationship between these measures employed samples of children or adolescents with brain disease/injury, ADHD, or who were typically-developing. Comparisons between the D-KEFS (objective) and BRIEF (subjective) among VLBW school-aged children in the current study yielded similar results as previously reported. Specifically, results indicate that (1) more children were identified as having significant EF difficulties on the D-KEFS than those identified on the BRIEF and (2) moderate, yet significant, correlations existed between some of the D-KEFS and BRIEF scales. These and the results of a chi-square test of independence suggest that there is a modest relationship between these measures and more children are identified as having EF impairments according to a performance-based measure than those identified according to parent report. The limitations and implications of these results are discussed.

Keywords: very low birth weight, preterm birth, behavior, executive functioning

TABLE OF CONTENTS

Page

LIST OF TABLES

INTRODUCTION

Recent advances in prenatal testing, obstetric care, and newborn intensive care technologies have greatly improved the survival rate of infants born prematurely and/or with low birth weight. The rate of infants born prematurely in the United States increased 6% between 1998 and 2008, with preterm births representing over 12% of all live births in 2008 (March of Dimes Foundation, 2011). An infant is considered premature if he or she is born prior to 37 weeks gestational age (GA). Lower gestational ages are typically associated with lower birth weights and most premature infants fall into one of three categories based on their weight at birth. Infants born with a birth weight (BW) at or below 2,500 grams (5 pounds, 8 ounces) fall into the low birth weight (LBW) category. A BW at or below 1,500 grams (3 pounds, 5 ounces) is classified as very low birth weight (VLBW) and a BW at or below 1,000 grams (2 pounds, 3 ounces) is classified as extremely low birth weight (ELBW). In the United States, 1.5% of all live births were VLBW and 6.7% were LBW in 2008 (March of Dimes Foundation, 2011).

The risks for adverse outcomes among these infants vary as a function of BW, with infants weighing less at a significantly higher risk for mortality and morbidity. Specifically, these infants are at risk for a variety of medical complications, including difficulties related to their underdeveloped brain, heart, lungs, gastrointestinal and digestive organs, which are all associated with long-term developmental and health-related problems. For instance, respiratory problems that call for oxygen supplementation (e.g., Bronchopulmonary Dysplasia [BPD]) have been associated with long-term cognitive, academic, visual-motor integration, behavior, attention, and executive functioning (EF) difficulties, while brain injuries such as Intraventricular Hemorrhage and seizures have also been related to neuromotor and intellectual delays later in life (Anderson & Doyle, 2006; Doyle & Anderson, 2009; Kessenich, 2003; Short et al., 2003). Not only are various medical complications associated with a number of impairments, but research has shown that the rate of these long-term difficulties is inversely proportional to the premature child's GA and BW. For example, worldwide rates of cognitive impairment throughout childhood range from 10% to 30% among children who are born at 25 weeks GA, 14% to 39% at 24 weeks, and 13% to 50% among infants with a BW less than 800 grams (1.76 pounds). Similarly, worldwide rates of neurodevelopmental disability among children born at 25 weeks GA range between 12% and 35%, rates at 24 weeks range from 22% to 45%, and rates among infants with a BW less than 800 grams range from 9% to 37% (Stephens & Vohr, 2009). With an increasing number of infants surviving who have lower BWs and earlier GAs, the risk of long-term problems is of considerable concern.

Others, however, have indicated that social/environmental factors may play an important role in children's long-term cognitive, behavioral and EF skills (Luu et al., 2011; Miller, Bowen, Gibson, Hand, & Ungerer, 2001). For example, two separate studies reported that maternal education is significantly associated with preterm adolescents' performance on EF measures (Luu et al., 2011) and with ELBW children's behavior problems at school-age (Miller et al., 2001).

The difficulties experienced by this population of children typically persist well into the school-age years. Results from a follow-up study in the United Kingdom and Ireland indicate that the rate of moderate to severe cognitive impairment among extremely preterm children (born at or before 25 weeks GA) at six years of age was 41%, compared to only 2% of their full-term, age-, race-, and gender-matched classmates. Furthermore, severe disability in these preterm children at 30 months was highly predictive of outcome at six years of age ($p < 0.001$), with 86% of preterm children with a severe cognitive disability at 30 months still classified as having a moderate to severe disability at six years (Marlow, Wolke, Bracewell, & Samara, 2005).

Although various risk factors for long-term cognitive, behavioral, and neuropsychological impairments have been identified, there is little consensus in the literature with regard to the specific factors that place preterm and LBW children at greatest risk for EF and behavioral difficulties. Thus, the primary purpose of the current study was to examine the degree to which neonatal/medical and social/environmental variables impact VLBW children's EF and behavioral abilities at school-age. Furthermore, given that many studies utilize only one measure to evaluate children's EF abilities, it is disconcerting that recent research has shown that subjective (i.e., parent-report) and objective (i.e., performance-based) EF measures often yield different results and have little or no association with one another (Bodnar, Prahme, Cutting, Denckla, & Mahone, 2007; Davis, Burns, Snyder, & Robinson, 2007; Vriezen & Pigott, 2002). Therefore, the secondary purpose of the current study was to explore the degree to which performance-based and parent rating measures of EF are related to one another.

The current study will review findings in the literature related to the impact of prematurity and LBW on childhood (a) cognitive, (b) neuropsychological/executive functioning, and (c) behavioral/attention abilities. In reviewing the literature on executive functioning and behavior/attention outcomes, research examining the risk factors related to these outcomes, including neonatal medical complications and environmental factors, will also be explored.

Cognitive Outcomes in the United States

Rates of cognitive and neurodevelopmental outcomes for children born prematurely and/or with LBW in the U.S. are similar to those previously reported in the United Kingdom and Ireland (Marlow et al., 2005) and have also been shown to be inversely proportional to the child's BW and GA (Andrews et al., 2008). A meta-analysis of 15 studies indicated that preterm children scored 10.9 points lower than full-term controls on measures of cognitive ability; however, these scores still fell within the average range among all studies examined (Bhutta, Cleves, Casey, Cradock, & Anand, 2002). Nonetheless, both GA and BW were found to be directly proportional to cognitive scores for both preterm and full-term children (Bhutta et al., 2002). More recently, data from the National Institute of Child Health and Human Development (NICHD) indicated that 23-30% of infants born between 27 and 32 weeks and 37-47% of infants born between 22 and 26 weeks GA experience significant cognitive impairment (Stephens & Vohr, 2009). Likewise, 28-40% of infants born between 27 and 32 weeks and 45-50% of infants born between 22 and 26 weeks GA display significant neurodevelopmental impairment (Stephens & Vohr, 2009). Taken together, these results indicate that not only in the U.S., but worldwide, preterm children's risk for long-term cognitive and neurodevelopmental impairments is significantly greater with lower BW and/or earlier GA.

Neuropsychological and Executive Functioning Outcomes

There is a wide array of adverse neuropsychological, or neurobehavioral, outcomes for children born preterm and with LBW, ranging from significant impairments in the form of major disabilities to more subtle difficulties. Approximately 12-25% of preterm children develop major disabilities such as cerebral palsy, blindness, deafness or significant hearing loss, and intellectual impairments including Intellectual Disabilities (Howard, Anderson, & Taylor, 2008). In addition to those preterm children with major disabilities, another 40-50% of preterm children experience less severe neurobehavioral impairments including learning disabilities, cognitive deficits (as indicated by a standard score equal to or less than 70 on cognitive measures), and behavior problems. Even among preterm infants who display no evidence of significant neurological impairments on neuroimaging scans, the incidence of neuropsychological deficits at the age of five has been shown to be as high as 46.5%, and includes neuromotor, language, visual, auditory, and behavioral difficulties (Fawer, Besnier, Forcada, Buclin, & Calame, 1995). It has also been shown that VLBW is associated with subtle, yet significant, neuropsychological deficits that persist well into young adulthood, even in the absence of neurosensory impairments (Strang-Karlsson et al., 2010). The specific neuropsychological deficits frequently reported among preterm youth include mild motor impairments, language difficulties, visual-motor deficits, inattention, slow processing speed, memory problems, and deficits in EF, such as reasoning ability, planning and organizational ability, and strategic decision making (Anderson & Doyle, 2004; Howard et al., 2008).

Executive functions are interconnected, neurocognitive processes which are responsible for planning and regulating goal-directed behaviors and cognitions. The executive functions include, but are not limited to, inhibition, working memory, attentional control, verbal fluency, cognitive flexibility, emotional and behavioral self-regulation, planning, organization, and goal selection. Preterm/LBW children are at a greater risk for impairments in EF and even subtle deficits in EF may negatively affect academic achievement, attention, and behavioral functioning (Aarnoudse-Moens, Smidts, Oosterlaan, Duivenvoorden, & Weisglas-Kuperus, 2009a; Anderson & Doyle, 2004). More specifically, deficits in various executive functions have been shown to contribute to difficulties in reading, writing, and mathematics, as well as attention and behavioral problems (Aarnoudse-Moens, 2009a; Hornby & Woodward, 2009; Sun, Mohay, & O'Callaghan, 2009). It is often the case that these problems are not evident until the prematurely-born/LBW child reaches school age. These areas of impairment are indicated by a greater need for educational support and the elevated frequency of school failure among these children (Briscoe, Gathercole, & Marlow, 2001; Marlow, 2004; Saigal et al., 2003; Stephens & Vohr, 2009). In fact, by the time they reach school-age, LBW and prematurely-born children are at a much higher risk for EF impairments than their normal birth weight (NBW) peers.

The higher rates of EF impairments in this population has been related to academic difficulties experienced by preterm children (Aarnoudse-Moens, Weisglas-Kuperus, van Goudoever, & Oosterlaan, 2009b; Marlow, Hennessy, Bracewell, & Wolke, 2007; Bayless & Stevenson, 2007; Fawke, 2007). Specifically, the literature consistently indicates that very preterm and VLBW children display explicit difficulties with three executive functions strongly related to academic achievement and/or behavioral functioning: holding information in the mind (i.e., working memory), switching between mental tasks (i.e., shifting or switching), and generating as many solutions for a problem as possible (i.e., cognitive flexibility) (Aarnoudse-Moens et al., 2009b).

Other investigators have provided insight into the specific executive functions in which impairments are present. For example, EF impairments have been identified in premature and LBW children at eight years of age, including specific deficits in reasoning ability, working memory, planning and organizational ability, and strategic decision making. These children also exhibited greater difficulty monitoring actions and shifting attention than did their NBW peers (Anderson & Doyle, 2004). More recently, results from a meta-analysis indicated that preterm and LBW children exhibit significant deficits in EF across the majority of measures administered, with greater deficits observed in visual-spatial reasoning and organizational tasks (Anderson & Doyle, 2008).

Moreover, impairments in EF can exist irrespective of overall intellectual ability (Edgin et al., 2008; Hornby & Woodward, 2009; Litt, Taylor, Klein, & Hack, 2005; Marlow et al., 2007; Taylor, Minich, Klein, & Hack, 2004). Given that deficits in EF are not solely restricted to children with global cognitive delay, and the role that these processes play in academic performance, it is possible that the EF deficits commonly exhibited among prematurely-born and LBW children may be one of the most significant challenges faced by these children when they reach school-age. Thus, it remains important to explore and identify the factors that place children at a greater risk for deficits in EF.

Executive Functioning and Neonatal Complications

Further support for the importance of EF in long-term outcomes in the preterm population can be found in the mediating effects of EF abilities. Specifically, the association between more severe neonatal complications and poorer academic achievement among ELBW children is significantly reduced when scores on neuropsychological tests (e.g., NEPSY) are included as a mediator (Taylor, Klein, Drotar, Schluchter, & Hack, 2006). In other words, more severe neonatal complications resulted in poorer academic achievement primarily as a result of their negative impact on EF abilities. Similarly, results from a structural equation model support the finding that VLBW children's neuropsychological ability mediates the relationship between BW and academic achievement (Taylor, Burant, Holding, Klein, & Hack, 2002).

In support of this finding, Howard and colleagues (2008) reported that preterm children and adolescents are at risk for a number of attention and EF impairments, with GA, BW, and medical complications in the neonatal period serving as the strongest predictors of long-term outcome. More specifically, inhibitory control, attention, and mental flexibility were strongly associated with premature birth itself (i.e., BW and GA), while working memory and planning deficits were more strongly related to medical complications, such as brain injury and respiratory problems (Howard et al., 2008). However, a more recent meta-analysis suggests a different trend, reporting that GA alone is consistently related to degree of impairment in attention, working memory, and planning skills among preterm children (Mulder, Pitchford, Hagger, & Marlow, 2009). In a population of VLBW adolescents, lower BW and longer period of oxygen requirement has been shown to predict greater visual-motor, memory, and EF impairments (Taylor, Minich, Bangert, Filipek, & Hack, 2004). Clearly there is little consensus in the literature with respect to the specific features of prematurity that impact various EF abilities, with GA, BW, brain injury, and respiratory difficulties all related to long-term deficits in several EFs.

Others, however, suggest that MRI abnormalities in the neonatal period (e.g., white matter injury, Intraventricular Hemorrhage [IVH]) are more strongly associated with neurodevelopmental outcome than birth status (Miller et al., 2005). However, Miller and colleagues (2005) used different measures of neurodevelopment than those typically used with school-age children, thus making it difficult to interpret these results relative to other studies of school-aged, preterm children. On the other hand, a study of very preterm adolescents found that severe brain injury on neonatal ultrasound was the most significant predictor of lower scores on standardized measures of EF (Luu, Ment, Allan, Schneider, & Vohr, 2011). Furthermore, recent studies have reported more optimal neurodevelopmental outcomes when neonatal neurological complications (e.g., IVH) are mild or absent (Baron, Ahronovich, Erickson, Gidley Larson, & Litman, 2009; Baron & Rey-Casserly, 2010; Edgin et al., 2008; Sherlock, Anderson, Doyle, & the Victorian Infant Collaborative Study Group, 2005).

The difficulty with interpreting these findings lies in the fact that the presence or absence of medical complications among preterm infants is often directly related to degree of prematurity, in that the likelihood of such complications occurring increases with lower GA and BW. Additionally, a consensus has not yet been reached regarding the impact of such risk factors on long-term outcome. For example, a study of preterm preschool-aged children demonstrated that white matter abnormality was more strongly related to impaired performance on EF measures than other medical factors (e.g., GA, IVH) (Edgin et al., 2008); however, research including adolescents and young adults born preterm suggests a *lack* of a significant relationship between performance on EF measures and GA, BW, or other perinatal variables, including white matter abnormalities (Nosarti et al., 2007; Rushe et al., 2001). Some have even reported that social or environmental factors play an important role in neurodevelopmental abilities, with one study indicating a significant relationship between higher maternal education and better performance on EF measures among very preterm adolescents (Luu et al., 2011). These studies suggest that neonatal medical factors may initially be related to children's EF earlier in life, but serve a less important role by adolescence when social/environmental variables are more strongly related to EF. Nonetheless, these conflicting findings suggest that further investigation of the relative contribution of these and other risk and protective factors on neurodevelopmental outcome of school-aged, preterm and LBW children is critically needed.

It remains clear that the mechanisms involved in EF deficits are not entirely understood to date, but specific risk factors have been identified including GA, BW, Bronchopulmonary Dysplasia, Intraventricular Hemorrhage, and maternal education (Anderson & Doyle, 2006; Howard et al., 2008; Luu et al., 2011; Taylor et al., 2004). However, research suggests that the impact of these risk factors differs across specific areas of EF skills (Howard et al., 2008; Mulder et al., 2009; Taylor et al., 2004), warranting further examination of the role of certain risk factors on these abilities. In summary, the aforementioned findings have important implications for the long-term academic outcomes of these at-risk children and highlight the importance of monitoring executive functioning skills among those children who experienced medical complications at birth.

Behavioral and Attention Outcomes

Behavioral and attention problems are also more common among children born premature and/or with LBW. A meta-analysis demonstrated that preterm children showed increases in externalizing and internalizing behavior problems in 13 out of 16 studies (81%) and increases in attention problems in 10 out of 15 studies (69%) (Bhutta et al., 2002). In six of these studies, a formal definition of Attention-Deficit/Hyperactivity Disorder (ADHD) was used, with results indicating that preterm children are more than twice as likely to have the disorder (relative risk = 2.64).

These problems are often seen across both the home and school settings and reported by multiple raters. For instance, both parents and teachers of 8- to 12-year-old VLBW and ELBW children reported significantly higher rates of inattention and hyperactivity compared to their NBW peers, with rates of 23-27% in VLBW and 33-37% in ELBW children (Stephens & Vohr, 2009). Parents of 5-year-old, very preterm children in France also reported significantly more behavioral problems (after adjustment for cognitive performance), with results indicating a twofold increase in the prevalence of hyperactivity, inattention, emotional symptoms, and peer problems when compared to full-term children (Delobel-Ayoub et al., 2009). Similar results were reported in a meta-analysis, in that the majority of studies indicated the presence of significant behavior problems related to attention, hyperactivity, self-esteem, internalizing, externalizing, and social problems among very preterm children at school-age (Anderson & Doyle, 2008). Moreover, evidence suggests that the relationship between cognitive ability and behavior is moderated by birth status; that is, the relationship between low IQ and behavioral problems is significantly more pronounced for preterm children than their full-term peers (Bayless, Pit-ten Cate, & Stevenson, 2008).

Not all research has reported elevated rates of behavior problems in the preterm and LBW population. One study conducted in Germany reported that 7-year-old LBW children were not significantly different from NBW controls with regard to hyperactive behavior (Pietz et al., 2004). Despite the use of a comprehensive sample of LBW children, these results must be interpreted with caution given that the overall sample size was relatively small, in addition to the fact that a brief, 10-item form of the Conners' scales was employed to assess behavior. It is possible that the lack of a significant finding between the LBW and NBW groups may be related to insufficient power to detect differences between groups. It is also possible that these findings are related to the use of a less thorough questionnaire to measure child behavior, and that the use of a more detailed rating scale may have captured between-group differences more effectively.

Others have also indicated relatively low levels of parent-reported attention problems, with less than 5% of the sample of VLBW preschoolers reported to have clinically significant levels of inattention, despite the fact that the VLBW preschoolers performed significantly worse than their NBW peers on computerized attention tasks (Davis et al., 2007). Given this finding, it is not surprising that this study also reported no significant association between parent ratings of attention problems and child performance on three attention tasks, suggesting that standard parent rating scales may not be sensitive measures of inattention challenges faced by the VLBW population. It is possible that the specific problems exhibited by preterm and LBW children are unique and may not be accurately captured by standard rating scales. This may be related to the fact that high levels of inattention and hyperactivity are common among preschoolers and standard rating scales for this population may actually be identifying the majority of preschoolers as exhibiting age-appropriate levels of inattention, whereas performance-based tasks may be more accurate in capturing significant difficulties with inattention. It is also often the case that attention problems do not become apparent until school age when demands for attention are much greater.

Like the cognitive and neurodevelopmental difficulties they experience, behavioral and attention difficulties seen among preterm and LBW children tend to persist well into adolescence. Adolescents born at or before 28 weeks GA continue to display significantly higher levels of parent- and teacher-reported hyperactivity, emotional, attention- and peer-related difficulties when compared to their full-term peers (Gardner et al., 2004). In fact, some have identified considerable increases in the proportion of preterm children with behavioral impairments as they become older, suggesting a propensity for worsening outcomes as preterm children progress through school (Hornby & Woodward, 2009). Consequently, it remains important to examine the behavior exhibited by preterm children at school-age and the factors related to adverse behavioral outcomes reviewed in the subsequent section.

Factors Related to Behavior and Attention Outcomes

With the preterm population at greater risk for long-term behavior and attention difficulties, it is imperative that research continues to identify variables that impact outcome. A study conducted in Australia reported that approximately 36% of their sample of ELBW children experienced clinically significant behavior problems at school-age, and that none of the measured neonatal or medical factors were related to behavioral outcomes. However, children with parent-reported behavior problems were more likely to have mothers who had not completed high school than those without behavior problems (Miller et al., 2001). Similarly, in a sample of 8-year-old German children, behavioral difficulties were considerably more extensive in children from adverse family backgrounds (e.g., low parent education, overcrowding in the home, marital discord, parental psychological disorders) than those who experienced medical complications at birth. Specifically, early family adversity was related to higher rates of behavior difficulties in a wide range of domains, whereas medical complications had a negative impact only on social and attention problems in children classified as "high-risk" (Laucht et al., 2000). However, this study provided little insight into the specific medical complications that impact social and attention difficulties in these "high-risk" children given that this risk category consisted of a significantly greater proportion of children with VLBW, lower Apgar scores, and respiratory distress at birth and the high-risk group as a whole spent significantly more days in the hospital. Thus, it is unclear which of these risk factors were related to the outcomes reported for this sample or which factors served a more important role than others. Nonetheless, this study illustrated that family adversity is more strongly related to a broader range of behavioral difficulties than medical complications at birth (Laucht et al., 2000).

Although the aforementioned findings provide some insight regarding the behavioral outcomes of preterm and LBW children at school-age, they must be interpreted with caution given that the samples consisted of German- (Laucht et al., 2000) and Australian-born (Miller et al., 2001) children where different cultural expectations of child behavior may be present. Studies conducted in the U.S., however, have found similar trends, reporting that higher SES was significantly related to fewer attention problems in VLBW children. This study also found that BW, but not GA, was related to attention; however, SES was more closely related to children's attention problems (Davis et al., 2007). Others have reported similar findings, noting that social/environmental risk factors, including maternal education and SES, were the major determinants of behavioral outcome at school-age (Hack et al., 1992). Taken together, these results provide support for the notion that as children get older, the impact of biological risk factors on developmental outcome decreases, while social or environmental factors become more influential, when major organ systems are not impaired (Fawer et al., 1995; Gross, Mettelman, Dye, & Slagle, 2001; Miceli et al., 2000; Miller et al., 2001).

On the other hand, a few studies have reported that social or environmental factors (i.e., SES) had no significant contribution to parent ratings of child behavior and that BW accounted for more variance in behavioral ratings (Conrad, Richman, Lindgren, & Nopoulos, 2010). The results of this study should be interpreted with caution given that the sample size was small and approximately 90% of the children received at least one blood transfusion during the neonatal period. Therefore, not only was there low statistical power to detect existing differences, but the sample may have been a unique subset of the preterm population, making it difficult to generalize these findings. A recent meta-analysis, however, provides further support for the notion that BW is an important risk factor for later behavioral difficulties. Specifically, LBW status was found to be a significant risk factor for ADHD that was not accounted for by environmental (e.g., SES), hereditary (e.g., parental ADHD or other behavior disorders), and other prenatal (e.g., maternal substance abuse) factors (Msall & Park, 2008). Yet another study illustrated that specific medical complications at birth are significantly associated with social competence in LBW toddlers (Landry, Chapieski, Richardson, Palmer, & Hall, 1990). In particular, Bronchopulmonary Dysplasia and severe grades of Intraventricular Hemorrhage (IVH) placed LBW children at higher risk for impairments in social development that persisted through age three years, whereas Respiratory Distress Syndrome and less severe grades of IVH did not (Landry et al., 1990). Additional examination of the behavioral sequelae among school-aged, preterm and LBW children is warranted in order to allow for an improved understanding of the risk factors that impact specific areas of children's long-term behavioral outcome.

Performance-Based Versus Informant Rating Measures

Given the plethora of literature indicating impairments in various aspects of EF, behavior, and neurocognitive abilities among the preterm population, it is important that these abilities are accurately measured. Many studies utilize parent-, teacher-, and/or self-report of difficulties in these areas, while others utilize performance-based measures of functioning. However, the literature has shown that performance-based (objective) and informant rating (subjective) measures of abilities often yield different results and are not always associated with one another (Anderson, Anderson, Northam, Jacobs, & Mikiewicz, 2002; Bodnar et al., 2007; Davis et al., 2007; Mahone & Hoffman, 2007; Rezazadeh, Wilding, & Cornish, 2011; Vriezen & Pigott, 2002). Specifically, when both types of EF measures are used, more children are identified as displaying impairments in EF according to subjective parent ratings (i.e., the Behavior Rating Inventory of Executive Function [BRIEF]) compared to objective performance-based measures (Bodnar et al., 2007; Vriezen & Pigott, 2002). Whereas other studies that utilized both objective and subjective measures of attention found the opposite trend, with less than 5% of a sample of VLBW preschoolers reported by parents to have clinically significant levels of inattention on a subjective measure (i.e., Child Behavior Checklist [CBCL]), despite the fact that they performed significantly worse than their NBW peers on objective computerized attention tasks (Davis et al., 2007).

One study used both objective and subjective measures of EF (e.g., performance-based computerized/paper-and-pencil tests and the BRIEF, respectively) to determine their predictive utility of ADHD status in a general clinical sample of children, finding that parent and teacher ratings on the BRIEF alone were significant predictors of ADHD status (Toplak, Bucciarelli, Jain, & Tannock, 2009). Additional analyses were conducted to examine this finding further, with results indicating that only a small amount of unique variance was attributable to performance-based measures in predicting ADHD status, whereas the majority of unique variance was attributable to parent and teacher ratings on the BRIEF, and there was little overlap in variance accounted for between the two types of measures (Toplak et al., 2009). This finding may be directly related to the fact that parents and teachers often yield a more accurate judgment of child behavior as a result of their more extensive exposure to the child, whereas performance-based assessments may not capture a child's true behavior in daily life.

In some cases, significant but modest associations were found between the BRIEF and children's performance on EF measures; however, each of the performance-based measures of EF was not uniquely related to its respective scale on the BRIEF (Mangeot, Armstrong, Colvin, Yeates, & Taylor, 2002; Toplak et al., 2009). Thus, it is possible that these measures assess different aspects of EF ability, with informant ratings measuring more of the behavioral characteristics of EF that impact day-to-day life and performance-based measures evaluating accuracy and speed of functioning. It is also important to note that the majority of research examining the relationship between subjective and objective measures of EF abilities employed samples of children or adolescents with brain disease/injury (Anderson et al., 2002; Mangeot et al., 2002; Vriezen & Pigott, 2002), ADHD (Mahone & Hoffman, 2007; Toplak et al., 2009), or those who were typically-developing (Bodnar et al., 2007; Rezazadeh et al., 2011). Therefore, it remains imperative that this issue be addressed with respect to the LBW preterm population given that these children are at high risk for EF impairments and, in recent years, there has been a greater emphasis on the evaluation of EF skills among these children.

Conclusion

Research conducted in recent decades has shown that children born preterm and with LBW are at greater risk for developing cognitive, neuropsychological, and/or behavioral impairments than their NBW full-term counterparts and that various medical and environmental factors play a significant role in long-term outcomes. However, there has been little consensus with regard to the specific factors that place preterm and LBW children at greater risk for EF and behavioral impairments, highlighting the significance of additional research to address this important issue. Given that EF, attention, and behavioral difficulties often co-occur in LBW preterm children and negatively impact academic performance, it is imperative that these outcomes, as well as the risk factors related to these outcomes, continue to be studied when these children reach school-age. Therefore, the primary purpose of the current study was to examine the impact of neonatal/medical and social/environmental variables on VLBW preterm children's executive functioning and behavioral abilities at school-age.

It is just as important that research continues to assess the accuracy of assessment tools commonly used to measure such abilities. This is particularly the case given that most studies use only one measure to assess children's abilities and recent research has shown that different types of measures have little or no association with one another. Specifically, performance-based (objective) and parent-report (subjective) measures of executive functioning and behavior often yield different results and lack significant intercorrelations. Thus, some children may be identified as delayed according to one measure, but not based on the results of another. Accordingly, the secondary purpose of the current study was to explore the degree to which performance-based and parent rating measures of executive functioning are related to one another.

CURRENT STUDY

Objectives

The primary objective of the current study was to examine the impact of neonatal/medical and social/environmental variables on VLBW children's executive and behavioral functioning at school-age. Examining the influence of various risk factors on VLBW children's behavior and executive functioning (EF) will expand on the current findings in the literature and may assist in identifying subgroups of children at greater risk for adverse outcomes at school-age. The secondary purpose of the current study was to explore the degree to which performance-based and parent rating measures of EF are related to one another. Such comparisons may allow for an enhanced understanding of the reliability of these measures in identifying impairments in various aspects of EF.

Aim 1

The primary objective of the study was to determine the variables that are most predictive of VLBW children's scores on measures of EF (i.e., the D-KEFS and BRIEF) and behavior (i.e., Conners' CBRS-P).

Hypothesis 1a. Recent research suggests that neonatal medical complications and birth status are the strongest predictors of preterm children's EF (Baron et al., 2009; Baron & Rey-Casserly, 2010; Edgin et al., 2008; Luu et al., 2011; Miller et al., 2005;

Sherlock et al., 2005); however, there is little consensus with respect to the specific features of prematurity that impact various EF abilities, with GA, BW, brain injury, and respiratory difficulties all related to long-term deficits. Furthermore, some have reported social factors (e.g., maternal education) play an important role in neurodevelopmental abilities (Luu et al., 2011). Such contradictory findings support the need for additional research. For the current study, it is hypothesized that neonatal factors such as BW, duration of oxygen requirement, and brain injury (i.e., IVH) will account for a significant amount of variance in children's EF skills (as measured by the D-KEFS and BRIEF), above and beyond social/environmental factors such as SES.

Hypothesis 1b. A number of studies have indicated that environmental factors, such as parental education and SES, are the primary determinants of behavioral and attention outcomes among preterm children at school-age (Davis et al., 2007; Hack et al., 1992; Laucht et al., 2000; Miller et al., 2001). Based on these findings, it is hypothesized that social/environmental factors (e.g., SES, maternal marital status) will account for a significant amount of variance in children's behavior (as measured by the Conners' CBRS-P), above and beyond neonatal/medical factors at birth (e.g., BW, brain injury, respiratory difficulties, etc.). However, others report that BW and specific medical complications at birth are associated with behavior (Conrad et al., 2010; Landry et al., 1990). Therefore, it is hoped that the results of the current study will assist in clarifying these conflicting findings.

Aim 2

The secondary objective of the current study was to compare VLBW children's performance on *performance-based* measures of executive function (i.e., D-KEFS) with *parent ratings* of executive function (i.e., BRIEF).

Hypothesis 2. Research has shown that when both types of EF measures are utilized, more children are identified as displaying significant impairments according to parent ratings compared to performance-based measures and these measures are not always associated with one another (Bodnar et al., 2007; Mangeot et al., 2009; Toplak et al., 2009; Vriezen & Pigott, 2002). Therefore, it is hypothesized that a greater percentage of children will be identified as exhibiting clinically significant difficulties in EF according to a parent rating measure (i.e., BRIEF) than those identified by a performance-based measure (i.e., D-KEFS) and that these measures will not be significantly associated with one another.

METHOD

Participants

The current study enrolled 60 children and their caregivers from two follow-up clinics in Birmingham and Tuscaloosa communities. Specifically, 50 children were recruited from the Neonatal Newborn Follow-up Clinic at the University of Alabama at Birmingham (UAB), and 10 were recruited from the Pediatric clinic through University Medical Center at the University of Alabama (UA), Tuscaloosa. Inclusion criteria for participants included age at assessment between 9 and 12 years, birth weight less than

1500g, and gestational age of 37 weeks or less. Children who experienced Intraventricular Hemorrhage (IVH), Bronchopulmonary Dysplasia (BPD), and/or Patent Ductus Arteriosus (PDA), or no major medical complication at birth were included. All three diagnoses were verified through medical records within each clinic. Follow-up testing for the current study occurred once the child reached 9 to 12 years of age and was conducted at one of the two locations (as described below).

Flyers describing the original study were mailed to the families of approximately 454 eligible children in various parts of the state. Follow-up phone calls were made to the 359 children for whom there was a phone number available in the database. In total, approximately 93 children (20%) were successfully located out of the original 454 potential participants. Approximately 28 families declined to participate, citing travel expenses, inability to take time off from work, and distance to the testing center. Four children were excluded from the study due to multiple disabilities and significant developmental delays that prevented accurate assessment using the study battery. One child's data was excluded due to a consensus between the family and the evaluator that the results obtained were not an accurate assessment of the child's current functioning due to behavioral difficulties during testing.

Children's age at assessment ranged from 9 to 12.92 years (M = 10.00, *SD* = 1.01). At birth, GA of the children ranged from 22 to 35 weeks (M = 27.32, *SD* = 2.47) and BW ranged from 385 to 1384 grams (M = 821.11, *SD* = 212.62). The length of time children remained in the NICU ranged from 4 to 28 weeks (M = 12.09, *SD* = 5.12) and length of time on mechanical ventilation ranged from 0 to 120 days (M = 36.81, *SD* = 38.72). In terms of medical complications at birth, 40.00% (n = 24) of children had BPD, 50.00% (n = 30) had PDA, and 31.67% (n = 19) had IVH. Of the 19 children with a diagnosis of IVH at birth, 47.36% (n = 9) had a Grade I bleed, 31.57% (n = 6) had a Grade II bleed, 5.26% (n = 1) had a Grade III bleed, and 15.79% (n = 3) had a Grade IV bleed, indicating that the majority of children (78.93%) experienced less severe brain bleeds. With respect to race, 53.33% (n = 32) of children were Caucasian, 35.00% (n = 21) were African American or African American/Caucasian, 10.00% (n = 6) were Hispanic or Hispanic/Caucasian, and 1.67% (n = 1) did not report race. More than half of the children were female (58.33%). The overall sample characteristics are presented in Table 1.

Table 1
Demographic Characteristics of the Sample

	%	*M* (range)
Child Characteristics		
Female gender	58.33	
Race/Ethnicity		
Caucasian	53.33	
African American or African American/Caucasian	35.00	
Hispanic or Hispanic/Caucasian	10.00	
Gestational Age, weeks		27.32 (22.00-35.00)
Birth Weight, grams		821.11 (385.00-1384.00)
Length of time in NICU, weeks		12.09 (4.00-28.00)
Length of time on mechanical ventilation, days		36.81 (0.00-120.00)
Intraventricular Hemorrhage		
Grade I	15.00	
Grade II	10.00	
Grade III	1.70	
Grade IV	5.00	
Bronchopulmonary Dysplasia	40.00	
Patent Ductus Arteriosis	50.00	
Age at assessment, years		10.00 (9.00-12.92)
WASI FSIQ		92.08 (56.00-127.00)
D-KEFS Scaled Score		
Tower		7.55 (1.00-16.00)
EF Composite		6.88 (1.00-12.00)
BRIEF, *T*-score		
Shift		52.92 (36.00-80.00)

BRI		51.28 (36.00-79.00)
MI		53.32 (35.00-73.00)
GEC		52.33 (35.00-77.00)
Conners' CBRS-P, *T*-score		
Hyperactivity/Impulsivity		54.83 (39.00-90.00)
ADHD Inattentive Type		57.91 (38.00-90.00)
ADHD Combined Type		54.83 (39.00-90.00)
Physical Symptoms		55.76 (38.00-90.00)
Family Characteristics		
Mother married, %	76.67	
Mother Education, %		
Less than High School Graduate	10.20	
High School Graduate	18.33	
Some College	30.00	
College Graduate	21.67	
Graduate or professional training	18.33	

Procedures

Researchers scheduled a 3-4 hour appointment to meet participants at either the Birmingham or Tuscaloosa clinic. Caregivers and children were consented for the study using the procedures approved by the UA and UAB IRB committees (see Appendix B for documentation of ongoing approval). Caregivers provided their consent and signed a medical release to allow researchers to access the child's birth records, while children provided their assent. Caregivers and children were assured that they were free to withdraw from the study at any time without any negative consequences. Caregivers were given a demographic form, the Behavior Rating Inventory of Executive Function (BRIEF) Parent Form, and the Conners' Comprehensive Behavior Rating Scale – Parent Report (Conners' CBRS-P) to complete while the child completed the battery of tests, both of which were used in the current analyses.

Each child was administered a battery of tests assessing a wide range of psychometric measures, taking approximately 3-4 hours to complete. The child measures included in the current analyses were the Wechsler Abbreviated Scale of Intelligence (WASI) and the Delis-Kaplan Executive Function System (D-KEFS). Child measures were counterbalanced to reduce the effects of fatigue on performance and breaks were taken as necessary to ensure the most reliable results possible. Upon completion of testing, participants received monetary compensation in the form of a gift card. Trained and supervised examiners were blind to the medical history of each child during administration of the battery. Information regarding the subject's condition was maintained by a research supervisor until all testing had been completed. All reasonable efforts were made to maintain participant confidentiality. All information was kept in a locked file cabinet in the principal investigators office. Each participant was assigned an ID number that was used to minimize the presence of identifying information on all protocols.

Measures

Demographic and Chart Review Information

A demographic form developed by researchers at UAB's Sparks Clinic was modified for use with this population. This survey included four forms: verification of optimal testing conditions, special education services, parent/child demographics, and child's medical history. The "verification of optimal testing conditions" form asked questions regarding the child's health at the time of testing, whether the child requires glasses/contacts or hearing devices, and whether the child had their glasses/contacts or hearing devices with them for testing. If the child did not have these objects or was too sick to allow for an accurate assessment of his/her ability, testing was rescheduled for a later date; however, there were no instances in which testing needed to be rescheduled for these reasons.

The “special education services” form contained questions regarding the services the child had received, as well as the time period the child received these services. The questions included in this form were broken down to measure the services received both before and after five years of age.

The “parent/child demographics” form was used to obtain information to calculate the two-factor form of the Hollingshead Index score (Hollingshead, 1965). This score was based on the occupation and education of all the employed adults supporting the household. Educational scores were based on the following scale:

1 = < 7 years of school,

2 = 7-9years of school,

3 = 10-11 years of school,

4 = high school graduate,

5 = 1-3 years of college,

6 = 4-year college degree, and

7 = professional degree.

Occupational scores were based on the following scale:

1 = farm or manual service workers (e.g., janitor, farm laborer, dishwasher),

2 = unskilled workers (e.g., waiter, garage worker, parking attendant),

3 = machine operators or semi-skilled workers (e.g., bus drivers, childcare workers, housekeepers),

4 = smaller business owners, craftspeople, and skilled workers (e.g., carpenter, mail carrier, plumber),

5 = clerical or salesworkers, and small-business owners (e.g., bank teller, telephone operator),

6 = semi-professionals (e.g., air traffic controllers, construction inspectors, sheriffs,)

7 = managers and minor professionals (e.g., social worker, teacher, real estate, agent),

8 = administrators and owners of mid-sized businesses (e.g., pilot, nurse, clergy person),

9 = professionals and large business owners (e.g., lawyer, civil engineer, architect).

The following formula was used to calculate the Hollingshead Index: Occupation x 7 + Education x 4 (Green, 1970; Hollingshead, 1965; Hollingshead, 1971). This score was calculated for all employed individuals residing in the household and then averaged to obtain a score for the household as a whole.

The “parent/child demographics” form was also used to obtain information to calculate a dichotomous variable of race and maternal marital status. Caregivers were asked to report their child’s race/ethnicity, listing all that apply, based on the following scale: 1 = Caucasian, 2 = African American, 3 = Hispanic American, 4 = Asian American, and 5 = Other. Race was then dichotomized as Caucasian (n = 32) versus Not Caucasian (n = 27) and utilized in all subsequent analyses. Maternal marital status was coded as 1 = married or 0 = not married, based on the following scale:

1 = Married and living with spouse (child's PARENT)

2 = Married and living with spouse (NOT child's PARENT)

3 = Married but living away from spouse

4 = Separated due to marital conflict

5 = Divorced

6 = Widowed

7 = Unmarried; living with boyfriend or mate (child's PARENT)

8 = Unmarried; living with boyfriend or mate (NOT child's PARENT)

9 = Unmarried; living alone (without mate)

Therefore, those who indicated that the mother's marital status was 1-3 were recoded as a 1 (i.e., married), while those who indicated 4-7 as the mother's marital status were recoded as a 0 (i.e., not married). This dichotomous variable was utilized in subsequent regression analyses. However, the original categorical variable with 9 levels was utilized in preliminary correlational analyses (Appendix A) to determine whether maternal marital status was correlated with any of the dependent variables (DVs) of interest. Descriptive statistics for maternal marital status are reported in Table 2.

Table 2
Maternal Marital Status of the Sample

	N (%)
Original Marital Status variable	
Married & living with spouse (child's parent)	43 (71.70)
Married & living with spouse (NOT child's parent)	2 (3.30)
Married but living away from spouse	1 (1.70)
Separated due to marital conflict	0 (0.00)
Divorced	3 (5.00)
Widowed	0 (0.00)
Unmarried; living with boyfriend or mate (child's parent)	0 (0.00)
Unmarried; living with boyfriend or mate (NOT child's parent)	2 (3.30)
Unmarried; living alone (without mate)	8 (13.30)
Dichotomous Marital Status variable	
Married	46 (76.67)
Not married	13 (21.67)

Finally, the "child's medical history" form was used to obtain the caregiver's account of the child's medical history at birth. This form also contained information on past medical and psychological conditions or diagnoses. In addition, a form was used for chart review that contained each child's gender, diagnoses, gestational age (weeks), birth weight (grams), length of time on mechanical ventilation (days), and length of hospital stay (weeks). With respect to neonatal medical diagnoses, each condition was coded as a dichotomous variable indicating the presence or absence of Intraventricular Hemorrhage (IVH), Bronchopulmonary Dysplasia (BPD), and/or Patent Ductus Arteriosus (PDA).

Global Cognitive Ability

WASI. The Wechsler Abbreviated Scale of Intelligence (WASI) was utilized to obtain a brief estimate of global cognitive functioning. The WASI consists of 4 core subtests from the longer versions of the Wechsler Intelligence Scale for Children (WISC), but only requires approximately 30 – 40 minutes to administer. Verbal IQ is comprised of scores from the Vocabulary and Similarities subtests, while Performance IQ is calculated from scores on the Block Design and Matrix Reasoning subtests. The Vocabulary subtest measures the child's word knowledge, while Similarities assesses the child's ability to integrate concepts and verbalize comparisons between ideas or objects. Block Design measures visual spatial integration and reproduction, requiring the child to replicate a pattern using between two and nine blocks. Matrix Reasoning taps similar skills, measuring the child's ability to visually identify the missing piece of complex patterns. All four subtests yield a Full Scale IQ (FSIQ) score and this score alone was used to control for the impact of children's overall intelligence on the DVs of interest. Internal consistency for this scale has been found to range from .81-.97 for children (Wechsler, 1999). For the current study, the internal-consistency reliability was .89. The WASI is correlated with the WISC (r = .86 between FSIQ scores for each measure; Wechsler, 1999) and was chosen for the study for its brevity and overall relationship to longer, more in-depth measures of intelligence.

Executive Function

Executive function was measured using two different formats: a subjective caregiver rating and an objective performance-based test of executive function.

Behavior Rating Inventory of Executive Function. The caregiver was asked to complete the Behavior Rating Inventory of Executive Function (BRIEF) Parent Form (Gioia, Isquith, Guy, & Kenworthy, 2000) as a subjective measure of executive function. The BRIEF can be used with children between 5 and 18 years of age and provides information pertaining to 8 domains of executive function skills: Inhibit (e.g., interrupts others), Shift (flexibility; e.g., becomes upset with new situations), Emotional Control (e.g., has overblown emotional outbursts), Initiate (e.g., needs to be told to begin a task even when willing), Working Memory (e.g., when given three things to do, remembers only the first or last), Plan/Organize (e.g., does not bring home homework, assignment sheets, materials, etc.), Organization of Materials (e.g., cannot find things in room or desk), and Self-Monitor (e.g., makes careless errors).

The BRIEF includes a list of statements that describe children's behavior, for which caregivers were asked to indicate if his/her child has had problems with any of the behaviors over the past six months (e.g., "Has trouble completing homework on time"). Caregivers are asked to indicate "N" if the behavior is Never a problem, "S" if the behavior is Sometimes a problem, and "O" if the behavior is Often a problem. Responses are then scored on 3-point Likert scale in which Never = 0, Sometimes = 1, and Often = 3. Scores from the Inhibit, Shift, and Emotional Control subscales are summed to obtain a Behavioral Regulation Index (BRI) score, while the remaining subscales are summed to obtain a Metacognition Index (MI) score. Scores from these two indices are then summed to obtain a Global Executive Composite (GEC) score. All scores on the BRIEF are subsequently converted to age- and gender-based *T*-scores with a mean of 50 and standard deviation of 10. The BRI, MI, and GEC scores were utilized as the primary DVs of interest for regression analyses in the current study. The internal-consistency reliability has been found to range between .80-.98 (Gioia & Isquith, 2004). For the current study, the internal-consistency reliability was .96.

Delis-Kaplan Executive Function System. Three subtests from the Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001) were administered as objective measures of executive function. Administration time for these three subtests of the D-KEFS is approximately 30 minutes. The Tower task requires a child to rearrange three disks on pegs to achieve a desired outcome, with the rules that only one disk can be moved at a time and a larger disk may never rest on top of a smaller one. This task requires the child to plan and organize the steps to complete the task and measures spatial planning, visual attention, rule learning, and impulse inhibition. Tower tests are commonly used measures of problem-solving and were developed to minimize the role of perceptual and motor skills, short-term memory, sustained attention, and verbal skills. The internal-consistency reliability for this task has been found to range from .43-.84 (Henry & Bettenay, 2010). The Sorting task is a planning task, measuring children's organizational problem solving and concept formation skills in both verbal and visuospatial domains. This task requires children to sort cards either by physical feature of the card (perceptual/ visuospatial) or by characteristics of the objects written on the card (verbal). The internal-consistency reliability for this task has been found to range from .55-.80 (Henry & Bettenay, 2010). For the current study, the internal-consistency reliability for this task was .96. The Trail Making task includes multiple conditions in which the child scans a series of numbers and letters and must either cross off a target number, connect letters or numbers in sequence, or connect alternating letters and numbers in sequence. The Trail Making task is a visual-motor task that assesses flexibility of thinking by measuring children's ability to shift between tasks, in addition to aspects of attention, speed of visual search, and visuomotor function. Internal consistency for this task has been found to range from .57-.79 (Henry & Bettenay, 2010). For the current study, the internal-consistency reliability for this task was .51. The internal-consistency reliability for all subscales of the D-KEFS was .72 for the current study.

Behavior/Attention

Conners' Comprehensive Behavior Rating Scale – Parent Report. Behavior and attention were measured according to caregiver report, in which caregivers were asked to complete the Conners' Comprehensive Behavior Rating Scale – Parent Report (Conners' CBRS – P; Conners, 1997) regarding their child. Caregiver report is a fundamental component of measuring behavioral difficulties in children given that caregivers are often most aware of such difficulties. The scale takes approximately 20 minutes to complete and consists of 203 items divided into 12 DSM-IV Symptom scales, including a DSM-IV: ADHD Predominantly Inattention Symptom scale and a DSM-IV: ADHD Predominantly Hyperactive-Inattention Symptom scale (referred to as ADHD Inattentive Type and Combined Type, respectively, hereafter). In addition to the 12 DSM-IV Symptom scales, items on the Conners' CBRS-P are divided into 8 Content scales: Emotional Distress, which is comprised of the Upsetting Thoughts, Worrying, and Social Problems subscales; Defiant/Aggressive Behaviors; Academic Difficulties, which encompasses the Language and Math subscales; Hyperactivity/Impulsivity; Separation Fears; Perfectionistic and Compulsive Behaviors; Violence Potential; and Physical Symptoms.

The Conners' CBRS-P includes a list of statements that describe children's behavior, for which caregivers were asked to indicate how well the statement describes his/her child's behavior in the past month (e.g., "Leaves seat when he/she should stay seated," "Worries about many things"). Responses are coded on a 4-point Likert scale in which 0 = Not true at all (Never, Seldom), 1 = Just a little true (Occasionally), 2 = Pretty much true (Often, Quite a bit), and 3 = Very much true (Very often, Very frequently). All scale scores are converted to age- and gender-based *T*-scores with a mean of 50 and standard deviation of 10. Total internal reliability coefficients range from .73-.94 (Conners, 1999). For the current study, the internal-consistency reliability was .92 for the Content scales and .93 for the DSM-IV Symptom scales.

RESULTS

Data Analysis

Preliminary Analyses

To examine the impact of neonatal/medical and social/environmental variables on VLBW children's executive functioning and behavioral abilities at school-age, a series of hierarchical multiple regression analyses were performed using the Statistical Package for Social Science (SPSS, version 11.5: Chicago, IL). Prior to conducting regression analyses, the data was examined for data-entry error, influential outliers, and missing data. Univariate and bivariate distributions of all variables were examined to screen for outliers and patterns of missing data. Less than 5% of data were missing and all data were determined to be missing at random. Analyses were conducted using pairwise deletion and listwise deletion, with results indicating that there were no relevant differences between the two methods. Given the small sample size of the current study, pairwise deletion was employed for all analyses to maximize the sample size. No influential outliers among the variables of interest were identified.

Descriptive statistics and scatterplots were obtained to ensure adherence to all assumptions of regression (i.e., normality, linearity, homoscedasticity, independence of errors, singularity, and multicollinearity). To examine for singularity and multicollinearity, correlations of the independent variables (IVs) were conducted and the correlation matrix was inspected to identify variables that were highly correlated ($r > 0.7$). Pearson's r was used to correlate parametric IVs, while Spearman's rho was used for nonparametric IVs. Correlations between variables are reported in Appendix A. High correlations were present between the following variables: length of hospital stay and gestational age (r = -.64); length of hospital stay and length of time on mechanical ventilation (r = .69); BPD and length of time on mechanical ventilation (r = .83). For the latter correlation, length of time on mechanical ventilation was used in all subsequent analyses instead of BPD, given that this variable is often used as a measure of severity of BPD (Ballard, Anstead, & Shook, 2007). For all additional regression analyses, each of the aforementioned variables was included alone as an IV of interest, determined by the degree to which each IV was correlated with each of the DVs of interest. No other violations of the assumptions of regression were identified. Correlations between the DVs of interest (scores from the D-KEFS, BRIEF, and Conners' CBRS – P scales) are presented in Table 3.

Table 3
Correlation Matrix of Dependent Variables of Interest

	1	2	3	4	5	6	7	8
1. Tower[a]	1.00							
2. EF[a]	.82**	1.00						
3. Shift[b]	-.26*	-.34**	1.00					
4. BRI[b]	-.37**	-.41**	.88**	1.00				
5. MI[b]	-.34**	-.39**	.72**	.73**	1.00			
6. GEC[b]	-.36**	-.41**	.86**	.92**	.91**	1.00		
7. Hyper/Imp[c]	-.17	-.18	.46**	.66**	.45**	.58**	1.00	
8. Inattentive[c]	-.26*	-.28*	.62**	.65**	.82**	.80**	.58**	1.00
9. Physical[c]	-.10	-.10	.46**	.44**	.49**	.51**	.28*	.39**

Note. N = 60. [a]D-KEFS. [b]BRIEF. [c]Conners' CBRS-P. EF = Executive Function Composite score; BRI = Behavioral Regulation Index; MI = Metacognition Index; GEC = Global Executive Composite; Hyper/Imp = Hyperactivity/Impulsivity scale; Inattentive = DSM-IV ADHD Predominantly Inattention Symptom scale; Physical = Physical Symptoms scale. *p < .05. **p < .01.

Aim 1

Hypothesis 1a. Bivariate correlations were initially conducted between all subtests of the D-KEFS and the medical and social IVs of interest (e.g., BW, GA, SES, etc.), indicating that scores from the Tower subtest alone were correlated with a number of IVs. Additionally, correlations among the three primary measures of executive function on the

D-KEFS (Trail Making shifting condition, Sorting, and Tower) were analyzed before creating a composite score for executive function (referred to as EF Composite score hereafter).

To analyze the independent contribution of the medical and social IVs of interest on children's EF scores, separate hierarchical regression analyses were employed for each of the DVs of interest. For each analysis, the child's age, gender, race, and IQ score from the WASI were entered in the first step to control for the impact of these factors on children's scores. In terms of the D-KEFS, regression analyses were conducted using (a) scores from the Tower subtest and (b) EF Composite scores separately as DVs. With respect to the BRIEF, regression analyses were conducted using the BRI, MI, and GEC scores as separate DVs.

The neonatal/medical variables that served as the primary IVs of interest included children's GA in weeks, BW in grams, presence or absence of medical complications (i.e., IVH, PDA), length of time on mechanical ventilation in weeks (which served as a measure of severity of BPD), and length of hospital stay in weeks. Inspection of the correlation matrix provided rationale for which of these IVs were utilized in subsequent analyses. For all analyses, only one of these IVs was entered to examine the degree to which the given neonatal factor impacted children's (a) Tower and (b) EF composite scores on the D-KEFS, as well as (c) BRI, (d) MI, and (e) GEC scores on the BRIEF.

The primary social/environmental variables serving as IVs of interest were maternal marital status and the two-factor form of the Hollingshead Index score for the household (i.e., SES; Hollingshead, 1965). When the correlation matrix indicated significant correlations between these IVs and the DV of interest, these social/

environmental variables were entered in the final step of the regression analysis to examine the degree to which maternal marital status or SES impacted children's EF scores from the D-KEFS and BRIEF.

Hypothesis 1b. The analyses described for *Hypothesis 1a* were employed in the same fashion for *Hypothesis 1b* to examine the independent contribution of neonatal/ medical and social/environmental factors on children's behavior. Bivariate correlations were initially conducted between all of the scales of the Conners' CBRS-P and the medical and social IVs of interest (e.g., BW, GA, SES, etc.). Inspection of the correlation matrix indicated significant correlations between a number of IVs of interest and the following Connors' CBRS-P scale scores: Hyperactivity/Impulsivity, Physical Symptoms, and ADHD Combined Type. Thus, only these scores were used as DVs of interest in subsequent hierarchical regression analyses.

For each regression analysis, the child's age, gender, race, and IQ score were entered in the first step to control for the impact of these factors on children's behavior. The neonatal/medical and social/environmental IVs that were significantly correlated with the DVs mentioned above were entered in Block 2 of the regression analyses to examine the independent contribution of these factors on children's CBRS-P scores.

Aim 2

Hypothesis 2. Descriptive statistics were employed to determine the percentage of children identified as having clinically significant difficulties with EF according to the D-KEFS and according to the BRIEF. Scores from the D-KEFS and BRIEF were dichotomized in order to identify the percentage of children with clinically significant difficulties according to each measure, as detailed below. Lower scores on the D-KEFS indicate greater difficulties with EF, while higher scores on the BRIEF indicate greater impairments. A score equal to or less than 1 standard deviation below the mean on the D-KEFS (i.e., scale score of 7 or below) was used to indicate significant difficulties. A score equal to or greater than 1 standard deviation above the mean on the BRIEF (i.e., *T*-score of 60 or higher) was used to indicate significant difficulties. A chi-square test of independence was also conducted to examine whether the BRIEF and D-KEFS are independent from one another by determining if there was a significant overlap between BRIEF GEC scores and D-KEFS Composite scores in the percentage of children identified as having difficulties.

To examine the degree to which the performance-based and parent rating measures are related to one another, correlational analyses were conducted between children's scores on the D-KEFS (Tower, Sorting, and Trail Making scores, which comprise the EF composite score) and on the BRIEF (BRI, MI, and GEC). Pearson correlation coefficients were calculated for all scores to examine the degree to which scores on the D-KEFS and the BRIEF are associated.

Primary Analyses

Aim 1

Hypothesis 1a. Table 4 displays the unstandardized regression coefficients (*B*), 95% confidence intervals, R^2, F, R^2-change, and F-change values for the significant regression analysis with EF scores as the DV of interest. In terms of children's D-KEFS scores, inspection of the correlation matrix indicated that children's Tower scale scores were significantly correlated with children's BW (r = .29), PDA (r = .46), and length of NICU stay (r = -.28). Thus, regression analyses were employed using each of these neonatal/medical IVs separately in Block 2 to determine their independent contribution on Tower scores. None of the regression analyses were significant after entry of control IVs in Block 1 and any of the 3 neonatal/medical IVs in Block 2. Children's EF Composite scores from the D-KEFS were significantly correlated with PDA (r = .49), length of mechanical ventilation (r = -.28), and length of NICU stay (r = -.34). None of the regression analyses were significant after entry of control IVs in Block 1 and any of the 3 neonatal/medical IVs in Block 2.

With respect to children's BRIEF scores, inspection of the correlation matrix indicated that none of the neonatal/medical or social/environmental IVs of interest were significantly correlated with either the Metacognition Index (MI) or the Global Executive Composite (GEC) scores; thus, regression analyses were not conducted using these DVs of interest. Children's Behavioral Regulation Index (BRI) scores, however, were significantly correlated with BPD (r = .27) and length of mechanical ventilation (r = .29). Subsequent regression analyses were conducted using length of time on mechanical ventilation as the IV of interest, with results indicating that entry of this IV in Block 2 approached significance in the amount of variance accounted for in children's BRI scores (p = .07). Given that the post-hoc power analyses reported previously revealed low power for detecting small effects, it is possible that that this finding may have a stronger level of significance given more statistical power. Nonetheless, this trend towards significance prompted exploratory analyses with subscale scores of the BRI (i.e., Inhibit, Shift, and

Emotional Control). None of the IVs of interest were correlated with the Inhibit or Emotional Control subscales; however, children's Shift scores were significantly correlated with BPD (r = .28) and length of mechanical ventilation (r = .32). After entry of all control IVs in Block 1, entry of length of time on mechanical ventilation in Block 2 accounted for an additional 6% of the variance in children's Shift scores, B = .08, R^2 = .26, F (5, 50) = 3.46, p < .05 (Table 4).

Table 4
Predictors of BRIEF Shift T-Scores

	BRIEF Shift *T*-Score		
		Model 2	
Variable	Model 1 *B*	*B*	95% CI
Constant	118.12***	110.52***	[64.34, 156.70]
Age	-3.33	-3.59*	[-6.79, -0.39]
Gender	1.58	1.48	[-4.55, 7.52]
Race	-0.83	0.38	[-5.94, 6.70]
Child's IQ	-0.36**	-0.30**	[-0.52, -0.08]
Mechanical Ventilation		0.08*	[0.00, 0.16]
R^2	0.19	0.26	
F	3.04*	3.46**	
ΔR^2		0.06	
ΔF		4.33*	

Note. N = 56. CI = confidence interval; Child's IQ = WASI FSIQ; Mechanical Ventilation = Length of time on mechanical ventilation in days. *p < .05. **p < .01. ***p < .001.

Hypothesis 1b. Tables 5-6 display the unstandardized regression coefficients (B), 95% confidence intervals, R^2, F, R^2-change, and F-change values for all significant regression analyses with Conners' CBRS-P scores serving as the DVs of interest. Inspection of the correlation matrix indicated significant correlations between a few of the CBRS-P scale scores and IVs of interest. Specifically, Hyperactivity/Impulsivity scores were significantly correlated with GA (r = -.27) and maternal marital status (r = .28); ADHD Combined Type scores were significantly correlated with GA (r = -.27) and maternal marital status (r = .28); and Physical Symptoms scores were significantly correlated with SES (r = -.32).

With respect to Hyperactivity/Impulsivity scores as the DV of interest, GA was entered in Block 1 (given the significant correlation between GA and Hyperactivity/ Impulsivity scores) in addition to all control IVs, while maternal marital status was entered in Block 2, to determine the amount of variance accounted for by maternal marital status above and beyond GA. After entry of all IVs in Block 1, entry of maternal marital status in Block 2 accounted for an additional 8% of variance in children's Hyperactivity/Impulsivity scores, $B = -10.83$, $R^2 = .26$, $F\ (6, 50) = 2.89$, $p < .05$ (Table 5).

Table 5
Predictors of Conners' Hyperactivity/Impulsivity T-Scores

	Conners' Hyperactivity/Impulsivity *T*-Score		
		Model 2	
Variable	Model 1 *B*	*B*	95% CI
Constant	141.37***	165.60***	[100.24, 230.96]
Age	-3.93	-4.32*	[-8.18, -0.47]
Gender	-4.17	-5.48	[-12.77, 1.82]
Race	4.67	1.43	[-6.47, 9.33]
Child's IQ	-0.16	-0.23	[-0.50, 0.04]
Gestational Age	-1.21	-1.15	[-2.64, 0.35]
Maternal Marital Status		-10.83*	[-20.09, -1.57]
R^2	0.18	0.26	
F	2.17	2.89*	
ΔR^2		0.08	
ΔF		5.51*	

Note. $N = 57$. CI = confidence interval; Child's IQ = WASI FSIQ. *$p < .05$. **$p < .01$. ***$p < .001$.

The regression analysis in which ADHD Combined Type scores served as the DV of interest yielded identical results as that with Hyperactivity/Impulsivity scores as the DV of interest, $B = -10.83$, $R^2 = .26$, $F\ (6, 50) = 2.89$, $p < .05$.This finding is not surprising given that the items that comprise the Hyperactivity/Impulsivity scale are also used to encompass children's ADHD Combined Type scores on the Conners' CBRS-P. In terms of Physical Symptoms scores as the DV of interest, after entry of control IVs alone in Block 1, entry of SES in Block 2 accounted for an additional 9% of variance in children's Physical Symptoms scores, $B = -.24$, $R^2 = .22$, $F\ (5, 48) = 2.64$, $p < .05$ (Table 6).

Table 6

Predictors of Conners' Physical Symptoms T-Scores

	Conners' Physical Symptoms *T*-Score		
		Model 2	
Variable	Model 1 *B*	*B*	95% CI
Constant	108.67***	119.39***	[59.08, 179.71]
Age	-4.43*	-4.63*	[-8.80, -0.46]
Gender	4.19	4.44	[-3.46, 12.33]
Race	3.07	1.83	[-6.35, 10.02]
Child's IQ	-0.21	-0.17	[-0.44, 0.12]
SES		-0.24*	[-0.44, -0.03]
R^2	0.13	0.22	
F	1.78	2.64*	
ΔR^2		0.09	
ΔF		5.45*	

Note. $N = 54$. CI = confidence interval; Child's IQ = WASI FSIQ. *$p < .05$. **$p < .01$. ***$p < .001$.

Secondary Analyses

Aim 2

Table 7 displays descriptive statistics of those children who were identified as having significant difficulties with EF according to the D-KEFS and the BRIEF.

Table 7

Descriptive Statistics of the D-KEFS and BRIEF

	Significant Difficulties*	
Scale	N	%
D-KEFS		
EF Composite Score	**34**	**56.7**
Tower	29	48.3
Sorting	36	60.0
Trail Making	29	48.3
BRIEF		
BRI	**17**	**28.3**
Inhibit	15	25.0
Shift	17	28.3
Emotional Control	15	25.0
MI	**19**	**31.7**
Initiate	8	13.3
Working Memory	26	43.3
Plan/Organize	16	26.7
Organization of Materials	10	16.7
Monitor	16	26.7
GEC	**17**	**28.3**

Note. $N = 60$. Composite Scores are in boldface. BRI = Behavioral Regulation Index; MI = Metacognition Index; GEC = Global Executive Composite.
*Score ≤ 7 for D-KEFS, Score ≥ 60 for BRIEF

Results indicated that 56.7% (n = 34) of children had a scale score of at least 1 standard deviation below the mean (i.e., ≤ 7) for the EF Composite Score of the D-KEFS. More specifically, 48.3% (n = 29) of children had a scale score in the significant range on the Tower subtest, 60% (n = 36) had a score in the significant range on the Sorting subtest, and 48.3% (n = 29) had a score in the significant range on the Trail Making subtest of the D-KEFS.

With respect to children's scores on the BRIEF, 28.3% (n = 17) had a standard score of at least 1 standard deviation above the mean (i.e., ≥ 60) for the Global Executive Composite (GEC) score. With respect to the specific Index scores that comprise the GEC score, 28.3% (n = 17) of children had a Behavioral Regulation Index (BRI) score and 31.7% (n = 19) had a Metacognition Index (MI) score in the significant range. More specifically, among the subscale scores that comprise the BRI, 25% (n = 15) of children had scores in the significant range for both the Inhibit and Emotional Control scales, while 28.3% (n = 17) children had scores in the significant range on the Shift scale. With respect to the subscales that constitute the MI score of the BRIEF, the following proportion of children had scores in the significant range for the following scales: 13.3% (n = 8) on the Initiate scale, 43.3% (n = 26) on the Working Memory scale, 26.7% (n = 16) on the Plan/Organize scale, 16.7% (n = 10) on the Organization of Materials scale, and 26.7% (n = 16) on the Monitor scale.

Table 8 displays the results of correlational analyses between children's scores on the D-KEFS (Tower, Sorting, and Trail Making scores, which comprise the EF

Composite Score) and on the BRIEF (BRI, MI, and GEC). Table 8 also displays correlations between each of children's D-KEFS scores and the subscales of the BRIEF.

Table 8
Correlations between D-KEFS and BRIEF Scales

	1	2	3	4
1. Trail Making	1.00			
2. Sorting	.43**	1.00		
3. Tower	.44**	.54**	1.00	
4. EF Comp	**.79****	**.81****	**.82****	**1.00**
5. Inhibit	-.14	-.43**	-.30*	-.36**
6. Shift	-.19	-.39**	-.26*	-.34**
7. EC	-.15	-.28*	-.32*	-.31*
8. **BRI**	**-.19**	**-.43****	**-.37****	**-.41****
9. Initiate	-.11	-.28*	-.33*	-.29*
10. WM	-.19	-.48**	-.33*	-.40**
11. Plan/Organize	-.11	-.46**	-.31*	-.36**
12. Organization	-.12	-.15	-.04	-.12
13. Monitor	-.26*	-.45**	-.33**	-.43**
14. **MI**	**-.20**	**-.43****	**-.34****	**-.39****
15. **GEC**	**-.16**	**-.47****	**-.36****	**-.41****

Note. $N = 60$. Composite Scores are in boldface. EC = Emotional Control scale; BRI = Behavioral Regulation Index; WM = Working Memory; Organization = Organization of Materials; MI = Metacognition Index; GEC = Global Executive Composite. *$p < .05$. **$p < .01$.

Specifically, significant correlations were present between children's Tower scores on the D-KEFS and all BRIEF scale scores, except the Organization of Materials subscale. Children's Tower scores were significantly associated with their BRIEF BRI scores (r = -.37), MI scores (r = -.34), and GEC scores (r = -.36). Children's Sorting scores on the D-KEFS were also significantly correlated with all BRIEF scale scores, except the Organization of Materials subscale. Children's Sorting scores were significantly associated with their BRIEF BRI scores (r = -.43), MI scores (r = -.43), and GEC scores (r = -.47). Finally, children's Trail Making scores on the D-KEFS were significantly correlated with the Monitor subscale alone on the BRIEF (r = -.26).

A chi-square test of independence was also conducted to examine whether the BRIEF and D-KEFS are independent from one another in the proportion of children identified as having significant difficulties with EF. The GEC score from the BRIEF and the EF Composite score from the D-KEFS were dichotomized and subsequently utilized as global scores of EF impairments, with 0 indicating no difficulty and 1 indicating significant difficulty (cut-off scores for each measure previously reported). The Pearson chi-square value approached significance (*p* = .052) indicating a trend towards a significant overlap between the measures in the proportion of children identified as exhibiting EF impairments (Table 9).

Table 9
Chi-Square Test between D-KEFS and BRIEF

	BRIEF GEC	
Scale	No difficulties	Significant difficulties
D-KEFS		
EF Composite Score		
No difficulties, N	22	4
Significant difficulties, N	21	13
Total, N (%)	43 (71.7)	17 (28.3)

Note. N = 60. *Score ≤ 7 for D-KEFS, Score ≥ 60 for BRIEF

More children were identified as having significant difficulties according to the EF Composite score from the D-KEFS (n = 34, 56.7%) than those identified as having significant difficulties according to the GEC score from the BRIEF (n = 17, 28.3%). Furthermore, 35% of children (n = 21) were identified as having significant difficulties with EF on the D-KEFS, while their caregivers reported the absence of difficulties on the BRIEF. Meanwhile, 36% of children (n = 22) were identified as having no difficulties with EF according to both measures, and 21.7% of children (n = 13) were identified as having significant EF difficulties according to both measures.

Post-Hoc Power Analysis

A post-hoc power analysis was conducted for hierarchical multiple regression analyses using G*Power © (Faul, Erdfelder, Lang, & Buchner, 2007). A sample size of 60 and a 6 predictor variable equation was used for the statistical power analysis. The effect size used for this assessment ranged between $f^2 = .06$ and $f^2 = .09$, indicating a small to medium effect size level (defined as $f^2 = .02\text{-}.15$; Cohen, 1977). The alpha level used for this analysis was $p = .05$. Post-hoc analyses revealed the statistical power for the current study ranged between .49-.67 for detecting an effect size between .06-.09. Thus, there was lower power than desired at this effect size level, with adequate power ≥ .80.

DISCUSSION

Research conducted in recent decades has shown that children born preterm and with LBW are at greater risk for developing neuropsychological and/or behavioral impairments than their NBW full-term counterparts and that various medical and environmental factors play a significant role in long-term outcomes. However, there has been little consensus with regard to the specific factors that place preterm and LBW children at greater risk for executive functioning (EF) and behavioral impairments, highlighting the significance of additional research to address this important issue.

Executive Functioning

Studies indicate that neonatal medical complications and birth status are the strongest predictors of children's EF skills; however, there is little agreement with respect to the specific aspects of premature birth that impact various EF abilities, with GA, BW, brain injury, and respiratory difficulties all related to long-term problems (Baron et al., 2009; Baron & Rey-Casserly, 2010; Edgin et al., 2008; Miller et al., 2005; Sherlock et al., 2005). Moreover, recent studies have suggested that social/environmental factors (e.g., maternal education) have a significant impact on children's neurodevelopmental skills (Luu et al., 2011). The current study, however, hypothesized that neonatal/medical factors (e.g., BW, length of time on mechanical ventilation, etc.) would account for a significant amount of variance in VLBW children's EF skills. The results of this study indicate that none of the measured neonatal/medical or social/environmental variables contributed to children's EF scores on a standardized, performance-based measure (i.e., D-KEFS). Furthermore, the only significant finding when parent ratings of children's EF skills were used (i.e., BRIEF) was that length of time on mechanical ventilation accounted for a significant amount of variance in children's scores on the Shift subscale (Table 4). The Shift scale of the BRIEF serves as a measure of children's flexibility in thinking about new situations, activities, or aspects of a problem (e.g., becomes upset with new situations). The key aspects of shifting include the ability to make transitions, solve problems flexibly, switch or alternate attention, and change focus from one topic to another (Gioia et al., 2000). This finding is in line with previous research indicating that longer period of oxygen requirement predicted greater global EF impairments (Taylor et al., 2004); however, it is in disagreement with others who have suggested that mental flexibility is associated with premature birth itself (i.e., BW and GA), while working memory and planning deficits were more strongly related to medical complications, such as respiratory problems requiring mechanical ventilation (Howard et al., 2008).

In the current study, length of time on mechanical ventilation accounted for only a small amount of variance (6%) in children's Shift scores; however, measures of birth status (i.e., BW, GA) did not account for a significant amount of variance in the current sample. This suggests that prematurity or LBW alone does not necessarily impact children's mental flexibility in the current sample, but the amount of time on mechanical ventilation does have a negative impact on this ability. Specifically, the positive value of the unstandardized regression coefficient (*B*) in the regression equation indicates that the greater the length of time on mechanical ventilation in the neonatal period, the more difficulties these VLBW children had with mental flexibility at school-age. Given that such a small amount of variance in children's Shift scores is accounted for by length of time on mechanical ventilation, and that the full model accounted for only 26% of the variance in Shift scores, it is likely that other unmeasured variables play a significant role in children's mental flexibility at school-age. Nonetheless, the results of the current study suggest that length of time on mechanical ventilation plays an important role in children's mental flexibility scores.

Behavior

Studies have indicated that environmental factors (e.g., SES, parental education) are the primary determinants of behavioral outcomes among school-aged preterm children (Davis et al., 2007; Hack et al., 1992; Laucht et al., 2000; Miller et al., 2001). However, other investigators suggest that BW and specific neonatal medical complications are associated with behavior (Conrad et al., 2010; Landry et al., 1990). The current study hypothesized that social/environmental factors (i.e., SES, maternal marital status) would account for a significant amount of variance in children's behavior, above and beyond neonatal medical complications. In terms of children's scores on the parent rating measure of behavior (i.e., Conners' CBRS-P), only a few significant findings emerged in the current study. Specifically, maternal marital status accounted for a significant amount of variance in children's Hyperactivity/Impulsivity scores (Table 5). Given that the maternal marital status variable used was a dichotomous variable in which 0 = not married and 1 = married, the negative value of the unstandardized regression coefficient (*B*) in the regression equation indicates an inverse relationship between these two variables. In other words, children's Hyperactivity/Impulsivity scores were lower when their mother was married. These results suggest that children from families in which the mother is *not* married exhibit significantly greater hyperactive and impulsive behavior problems. This finding is supported by previous research in which behavioral difficulties were considerably more extensive in children from adverse family backgrounds (e.g., low parent education, overcrowding in the home, marital discord, parental psychological disorders) than those who experienced medical complications at birth (Laucht et al., 2000). However, none of the other measured social/environmental (i.e., SES) or neonatal/medical variables in the current study were related to children's Hyperactive/Impulsive or other behavior problems. Again, only 26% of the variance in children's Hyperactivity/Impulsivity scores was accounted for by the full regression equation with maternal marital status in the final step, indicating that a number of other unmeasured variables are likely related to children's hyperactive and impulsive behavior at school-age. Nonetheless, the results of the current study suggest that children's hyperactive and impulsive behavior is significantly related to maternal marital status.

Given that children's hyperactive/impulsive behavior was measured by parent report, this finding can be interpreted in a number of different ways. It is possible that mothers who are not married report their child to be significantly more hyperactive and impulsive because they lack the support from a spouse in disciplining or managing the child's behavior, making their child's behavior *appear* more difficult to manage. It is also plausible that mothers who are not married report that their child displays significantly more hyperactive and impulsive behavior because the child is "acting out" and this behavior is related to the absence of an additional disciplinary figure. This difficulty with interpretation is inevitable when interpreting results of parent reports of child behavior. Additionally, the cross-sectional nature of these data make it impossible to determine a causal effect; thus, it is not appropriate to conclude that having a mother who is not married causes a child to display more hyperactive/impulsive behavior, nor is it appropriate to conclude that these childhood behavior problems cause marital discord and subsequent separation. However, the results of the current study still provide insight in indicating a significant association between maternal marital status and children's hyperactive and impulsive behavior.

Additionally, the current results indicate that SES accounted for a significant amount of variance in children's Physical Symptoms scores (Table 6). The negative value of the coefficient in the regression equation indicates that with lower SES, children have higher Physical Symptoms scores. In other words, children from families with lower SES may be exhibiting a greater number of physical or somatic symptoms/complaints (e.g., "complains about stomach aches"). This finding can be interpreted in a number of ways. It is possible that children from families with lower SES actually experience a greater number of physical symptoms due to factors such as poor diet or suboptimal medical treatment. Poor diet or sleep habits are more prevalent in lower SES families, and these factors may contribute to children's physical symptoms (e.g., lack of sleep often leads to headaches and/or stomach aches in both adults and children). Additionally, limited resources may prohibit lower SES families from obtaining appropriate and effective medical treatment when children's physical symptoms initially emerge, potentially leading to worsening or continuous physical complaints in the child. Again, given the cross-sectional nature of these data, it is not possible to conclude a causal relation between SES and children's physical symptoms. However, the current study indicates the presence of a significant relation between SES and physical symptoms in the current sample of VLBW children at school-age.

The Importance of Clinic Site

All of the aforementioned regression analyses were re-analyzed controlling for clinic site and when using children from UAB alone to examine the degree to which clinic site impacted the results. All significant findings from the regression analyses reported above were no longer significant after controlling for clinic site. This same finding occurred when using children from UAB alone (i.e., excluding the 10 participants from UA in Tuscaloosa). These results may be due to the fact that children recruited from Tuscaloosa, on average, had higher scores (indicating greater difficulties) on some of the DVs of interest. However, an ANOVA indicated a significant difference between sites *only* for children's Physical Symptoms scores ($p < .05$), but not for any of the other DVs. Thus, the fact that the original regression analyses indicated that SES accounted for a significant amount of variance in children's Physical Symptoms scores (Table 6), whereas these results are no longer significant when controlling for clinic site, may be due to one of two issues: (1) caregivers of children from Tuscaloosa reported significantly greater difficulties with Physical Symptoms compared to children from UAB. Specifically, the average score on the Physical Symptoms scale for children from UAB was 53.71 (SD = 13.64) and for children from Tuscaloosa was 66.89 (SD = 17.86). Alternatively, (2) the results of the ANOVA also indicated a significant difference between sites for SES ($p < .05$), in that the average SES for children from UAB was significantly higher (M = 52.15, SD = 19.07, range = 16-84) than that for children from Tuscaloosa (M = 34.07, SD = 15.70, range = 14-55). Thus, children from UAB came from families with significantly higher SES than children in Tuscaloosa. Therefore, it is possible that the significant relation initially found between SES and children's Physical Symptoms scores is largely explained by the subset of participants in Tuscaloosa. This would explain the fact that this significant finding disappeared when controlling for clinic site or when excluding children from Tuscaloosa.

Furthermore, a chi-square test of independence indicated a significant difference between sites for the dichotomous variable, maternal marital status ($p < .05$). Specifically, a greater percentage of mother's from UAB were married (84%, n = 42 vs. not married = 16%, n = 8) compared to mother's from UA in Tuscaloosa (40%, n = 4 vs. not married = 50%, n = 5). Thus, the fact that the initial regression analysis between maternal marital status and children's Hyperactive/Impulsive scores indicated a significant relationship (Table 5), whereas this relationship was no longer significant when controlling for clinic site or when excluding children from Tuscaloosa, may be due to the fact that the majority of children from UAB had mothers who were married and the opposite was true for children from Tuscaloosa. In other words, the finding that greater difficulties with hyperactive and impulsive behavior existed for children whose mother was *not* married may be largely attributable to the larger proportion of unmarried mothers from Tuscaloosa.

Lastly, with respect to the initial regression analysis in which length of mechanical ventilation accounted for a significant amount of variance in children's Shift scores (Table 4), this relationship too was no longer significant when controlling for clinic site. However, results of an ANOVA indicated that both children's Shift scores and length of time on mechanical ventilation did not differ significantly between clinic sites. Despite the lack of a statistically significant difference between sites, the length of time on mechanical ventilation for children from Tuscaloosa was higher than that for children from UAB. Specifically, the average time on mechanical ventilation for children from UAB was 34.87 days (SD = 35.58), while the average time on mechanical ventilation for children from Tuscaloosa was 45.90 days (SD = 52.41). Again, the fact that children from Tuscaloosa spent, on average, more time on mechanical ventilation may explain the fact that the initial regression analysis was no longer significant when controlling for clinic site or excluding children from Tuscaloosa. These findings depict a clear limitation of the current study.

Performance-Based Versus Informant Rating Measures

Research has shown that when both types of EF measures are utilized, more children are identified as displaying significant impairments according to parent ratings compared to performance-based measures and these measures are not always associated with one another (Bodnar et al., 2007; Mangeot et al., 2009; Toplak et al., 2009; Vriezen & Pigott, 2002). However, this has yet to be examined using a preterm LBW population. The current study hypothesized a similar trend would emerge among this sample of VLBW preterm children at school-age; however, the results of the current study did not entirely support this hypothesis. Results indicated that more children were identified as having global EF impairments on the standardized, performance-based measure (i.e., D-KEFS) compared to the parent rating measure of EF (i.e., BRIEF). Specifically, 56.7% (n = 34) of children exhibited significant difficulties according to the global composite score of D-KEFS, while only 28.3% (n = 17) of children were reported by caregivers as having significant difficulties according to the Global Executive Composite (GEC) score of the BRIEF. Furthermore, only a few significant correlations existed between children's scores on the D-KEFS and the BRIEF. With respect to the global EF composite score of the D-KEFS and the Index scores on the BRIEF, correlations were significant but modest with coefficients ranging from -.39 (between the D-KEFS composite score and the BRIEF Metacognition Index [MI] score) and -.41 (between the D-KEFS composite score and both the BRIEF Behavioral Regulation Index [BRI] and GEC scores), suggesting some overlap between these two measures of EF ($p < .01$; Table 8). The results of the current study suggest that there is in fact some agreement between the performance-based and parent rating measures of EF in terms of identification of those VLBW children who exhibit significant difficulties with EF. However, parent ratings in the current study identified fewer children as displaying significant EF difficulties, a finding that is consistent with previous research examining the agreement between measures of attention (Davis et al., 2007). However, other investigators who have also used the BRIEF as a parent rating of EF found the opposite trend (Bodnar et al., 2007; Vriezen & Pigott, 2002).

It is possible that the performance-based measure used in the current study (i.e., D-KEFS) is more sensitive to EF impairments than parent ratings of EF, as well as some of the other measures used in previous research (e.g., Conners' CPT, Bodnar et al., 2007). The finding that parent ratings on the BRIEF identified fewer VLBW children as exhibiting significant EF difficulties than the D-KEFS did may also be related to the fact that parents (unlike teachers) often lack a comparison group to compare their own child's behaviors and abilities against. This can make it difficult for parents to accurately report the presence of problems or difficulties in their child if they do not have a "norm" to compare their child's abilities to. Nonetheless, the results of the current study address a gap in the literature by utilizing a cohort of VLBW preterm children given the recent increase in research examining EF outcomes among this subgroup of children. Furthermore, these results indicate that use of parent ratings alone may underestimate the proportion of VLBW children displaying significant EF difficulties and additional measures of EF should be used.

Limitations

The current study was limited by several methodological shortcomings. First, the current sample is small ($N = 60$) and post-hoc power analyses indicated lower power than desired to detect existing effects. With a larger sample size, some of the results that were nonsignificant or approached significance may have emerged as statistically significant.

Although some significant results emerged in the current study, additional research with larger sample sizes is necessary in order to confirm these findings. Second, a number of the measures used in the current study were caregiver report. Caregivers may have intentionally or unintentionally misreported information regarding their child's behavior and executive functioning. The addition of teacher report to corroborate caregiver report may have provided a more reliable measure of child abilities. Additionally, the current data were cross-sectional, complicating the interpretation of the results of the regression analyses. For example, the current study found that maternal marital status accounted for a significant amount of variance in children's hyperactive/impulsive behaviors; however, the cross-sectional nature of the data make it impossible to conclude the direction of this relationship. Longitudinal research that can evaluate behavioral outcomes may clarify this relationship. Furthermore, a small proportion of the participants were of multiple gestation, with data collected from four sets of twins and two sets of quadruplets. The use of data from multiples violates an important assumption of regression analyses, which assumes that the data are independent from one another. Undoubtedly, data from children of multiple gestation are not independent, as these children share extensive genetic and environmental commonalities, and this is a clear limitation of the current study. However, exclusion of these children from statistical analyses would significantly reduce the variability in the data, in turn, reducing the study's power to detect significant results. Therefore, these children were not excluded from the current study's analyses.

The inability to follow up the majority of families from the original database is another major limitation of the current study. Given that children were followed 9 to 12 years after birth for the current study, contact information for the majority of families were no longer applicable since many families had moved or changed their contact information during the course of this 9- to 12-year period. The primary goal of the current study was to examine behavioral and executive functioning in children at school-age and, thus, a large gap between birth and follow up was inherent, making it inevitable that the majority of families would be difficult to contact. However, it is important to keep this limitation in mind when interpreting the results of the present study given the possibility that those families lost to follow-up may have been significantly different from the current sample in a variety of ways. These limitations indicate the need to replicate the current study's findings with a larger sample size, using more reliable measures of child abilities, and using a longitudinal study design.

IMPLICATIONS AND FUTURE DIRECTIONS

While the rates of survival for infants born prematurely have increased substantially in the last decade, the rates of subsequent morbidity among these high-risk children have, in turn, increased as well. With over 540,000 infants born prematurely annually, this translates to an enormous economic burden associated with preterm birth in the U.S., estimated at more than $26.2 billion of medical, educational, and lost productivity costs in 2005 (March of Dimes Foundation, 2011). During the first year of life, medical costs alone are, on average, approximately ten times greater for preterm infants compared to term infants, with the cost of inpatient and outpatient care for preterm children averaging $32,325 in 2005, compared to only $3,325 for term children (March of Dimes Foundation, 2011).

The fact that many of the difficulties these children experience persist well beyond the school-age years, and that the medical complications these children often experience are largely unavoidable, it is important to examine the degree to which various neonatal and environmental factors impact children's EF and behavioral outcomes. Given that deficits in various executive functions contribute to academic, attention, and behavior problems, and that both behavior and EF have an enormous impact on children's ability to perform in an academic setting (Aarnoudse-Moens et al., 2009a; Aarnoudse-Moens et al., 2009b; Hornby & Woodward, 2009; Sun et al., 2009), it remains imperative that these outcomes are closely monitored and risk factors continue to be identified. Results from the current study may allow professionals to more easily identify those preterm children at increased risk for problems later in life. For example, our results suggest that children who required more time on mechanical ventilation during the neonatal period may be at higher risk for difficulties with mental flexibility, children being raised by a single mother may be at higher risk for hyperactive and impulsive behaviors, and children from lower SES may be at higher risk for physical symptoms or complaints at school age. Increased awareness of those preterm children at greater risk for long-term difficulties could potentially allow professionals to address and treat impairments as early as possible, in turn reducing the costs associated with these difficulties.

It is important that this area continue to be studied, particularly with the use of a larger sample size and a longitudinal study design. Longitudinal research, in which neonatal medical and environmental factors are measured early, while children's EF and behavior are measured at school-age, would provide additional insight as to whether such factors have a direct influence on these child outcomes. Future longitudinal research would also involve recurring contact with families of preterm and/or LBW children as they progress through school and this may allow researchers to more easily maintain contact with these families, reducing the number of participants lost to follow up (an issue faced by the current study).

Since their development, there has been much interest in the clinical utility of executive function measures, including both performance-based and informant ratings of abilities. Much research has focused on measuring convergence across different types of measures and findings appear to be somewhat mixed (Anderson et al., 2002; Bodnar et al., 2007; Davis et al., 2007; Mahone & Hoffman, 2007; Mangeot et al., 2002; Rezazadeh et al., 2011; Toplak et al., 2009; Torrioli et al., 2000). With respect to measures of EF, a number of studies indicate modest or no significant associations between performance-based measures and the BRIEF (Mangeot et al., 2002; Toplak et al., 2009); however, most research has utilized samples of children or adolescents with brain disease/injury (Anderson et al., 2002; Mangeot et al., 2002; Vriezen & Pigott, 2002), ADHD (Mahone & Hoffman, 2007; Toplak et al., 2009), or those who were typically-developing (Bodnar et al., 2007; Rezazadeh et al., 2011). Thus, the fact that the results of the current study indicate similar findings when using a sample of preterm VLBW children addresses a critical gap in the literature, given that these children are at a much higher risk for EF difficulties than their NBW peers and these types of measures are commonly used to measure their abilities. The fact that more children were identified as having significant EF difficulties according to a performance-based measure than an informant rating measure suggests that the use of subjective measures alone may not sufficiently identify those children experiencing problems. Professionals should, therefore, be cautioned when using subjective measures alone to measure children's EF and, when possible, both performance-based and subjective measures should be used to obtain a more accurate depiction of children's true EF abilities.

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APPENDIX A

CORRELATION MATRIX OF PREDICTORS & CHILD OUTCOMES

Correlation Matrix of Predictors & Child Outcomes

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Age	1.00												
2. Gender[a]	-.05	1.00											
3. Race[a]	.15	.17	1.00										
4. GA	.05	-.15	-.11	1.00									
5. BW	-.09	-.32*	.00	.58**	1.00								
6. IVH[a]	.10	-.05	.04	-.19	-.03	1.00							
7. BPD[a]	.04	-.03	.02	-.63**	-.47**	.15	1.00						
8. PDA[a]	-.33*	-.06	-.24	-.12	.12	.08	-.05	1.00					
9. O_2	.19	-.02	-.05	-.62**	-.55**	.20	.83**	.06	1.00				
10. NICU	.30*	.07	-.04	-.65**	-.53**	.19	.61**	.18	.69**	1.00			
11. IQ[b]	-.40**	-.01	-.30*	.25	.32*	-.11	-.26	.49**	-.31*	-.44**	1.00		
12. SES	-.13	.02	-.18	.07	-.16	-.23	.13	.24	-.00	-.02	.22	1.00	
13. Maternal Marital Stat[a, c]	.07	.27*	.46**	-.05	.10	.07	.04	.09	.05	-.03	.07	-.39**	1.00
14. Tower[d]	-.36**	-.12	-.15	.18	.29*	-.18	-.19	.46**	-.22	-.28*	.63**	.12	.05
15. EF[d]	-.31*	.02	-.19	.22	.25	-.13	-.23	.49**	-.28*	-.34*	.79**	.24	.02
16. Shift[e]	-.10	.07	.08	-.21	-.18	.06	.28*	-.09	.32*	.20	-.35**	.09	.01
17. BRI[e]	-.04	.06	.18	-.19	-.14	.14	.27*	-.11	.29*	.22	-.39**	.07	.07
18. MI[e]	-.05	.16	.12	-.04	-.12	.02	.14	-.16	.12	.08	-.39**	-.02	.04
19. GEC[e]	-.03	.15	.19	-.11	-.17	.10	.24	-.18	.23	.16	-.43**	.03	.08
20. Hyper/Imp[f]	-.19	-.13	.18	-.27*	-.01	.14	.17	.11	.13	.17	-.16	-.05	.28*
21. Inattentive[f]	-.07	.16	.27*	-.23	-.08	.02	.18	-.04	.12	.08	-.32*	-.01	.17
22. Combined[f]	-.19	-.13	.18	-.27*	-.01	.14	.17	.11	.13	.17	-.16	-.05	.28*
23. Physical[f]	-.20	.06	.05	-.00	.22	.14	.02	-.04	-.07	-.04	-.13	-.32*	.21

Note. $N = 60$. [a]Nonparametric correlations. [b]Child's WASI FSIQ. [c]Correlations with Maternal Marital Status were conducted prior to dichotomizing this variable. [d]D-KEFS. [e]BRIEF. [f]Conners' CBRS-P. GA = Gestational Age; BW = Birth Weight; IVH = Intraventricular Hemorrhage; BPD = Bronchopulmonary Dysplasia; PDA = Patent Ductus Arteriosis; O_2 = Length of Mechanical Ventilation (days); NICU = Length of hospital stay (weeks); EF = Executive Function Composite Score (Trail Making, Sorting, and Tower subtests). *$p < .05$. **$p < .01$.

APPENDIX B

UAB IRB APPROVAL

12-9-11
JJN

THE UNIVERSITY OF
ALABAMA AT BIRMINGHAM

Institutional Review Board for Human Use

Form 4: IRB Approval Form
Identification and Certification of Research
Projects Involving Human Subjects

UAB's Institutional Review Boards for Human Use (IRBs) have an approved Federalwide Assurance with the Office for Human Research Protections (OHRP). The Assurance number is FWA00005960 and it expires on August 29, 2016. The UAB IRBs are also in compliance with 21 CFR Parts 50 and 56.

Principal Investigator: DE JONG, DESIREE MARIA

Co-Investigator(s):

Protocol Number: **X081118010**

Protocol Title: *Cognitive profiles of medical morbidities associated with premature birth: A study of children with BPD, IVH, and/or PDA*

The IRB reviewed and approved the above named project on 12-9-11. The review was conducted in accordance with UAB's Assurance of Compliance approved by the Department of Health and Human Services. This Project will be subject to Annual continuing review as provided in that Assurance.

This project received EXPEDITED review.

IRB Approval Date: 12-9-11

Date IRB Approval Issued: 12-9-11

Marilyn Doss

Marilyn Doss, M.A.
Vice Chair of the Institutional Review
Board for Human Use (IRB)

Investigators please note:

The IRB approved consent form used in the study must contain the IRB approval date and expiration date.

IRB approval is given for one year unless otherwise noted. For projects subject to annual review research activities may not continue past the one year anniversary of the IRB approval date.

Any modifications in the study methodology, protocol and/or consent form must be submitted for review and approval to the IRB prior to implementation.

Adverse Events and/or unanticipated risks to subjects or others at UAB or other participating institutions must be reported promptly to the IRB.

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