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Cognitive Predictors of Academic Achievement in Young Children 1 Year Following Traumatic Brain Injury

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Abstract

Objective—To examine cognitive predictors of academic achievement in young children with traumatic brain injury (TBI) and orthopedic injury (OI) shortly after injury and 1 year post-injury.

Methods—Participants included 3 to 6 year old children, 63 with TBI (46 with moderate TBI and 17 with severe TBI) and a comparison group of 80 children with OI. Academic achievement was assessed approximately 1 month and 12 months post injury, using three subtests from the Woodcock-Johnson Tests of Achievement-Third Edition and the School Readiness Composite from the Bracken Basic Concepts Scale-Revised. General intellectual functioning, memory, and executive functions were measured at the initial assessment using standardized tests.

Results—Hierarchical linear regression was used to predict academic achievement at the initial and 1-year follow-up assessments. Memory and executive functions were significant predictors of academic achievement at both assessments, after controlling for group membership and demographic variables. Executive function remained a significant predictor of some outcomes after taking general intellectual functioning into account. Predictive relationships did not vary across the TBI and OI groups. Similar results were obtained when regression analyses were completed with only TBI participants using the Glasgow Coma Scale (GCS) score as a predictor, although memory and executive functioning were somewhat less robust in predicting academic achievement than before.

Conclusions—Both memory and executive function predict academic achievement following TBI in preschool children, although some of the associations may be accounted for by general intellectual functioning.

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Keywords

Traumatic brain injury (TBI); preschool children; academic achievement; memory; executive function

INTRODUCTION

Traumatic brain injury (TBI) is one of the most common causes of death and long-term disability in children. Over half a million children under age 15 sustain a TBI each year in the United States (Faul, Xu, Wald, & Coronado, 2010; Kraus, 1995). Negative outcomes among survivors of TBI include deficits in academic achievement and school performance that occur in combination with physical disabilities, deficits in cognitive skills, and problems in behavioral adjustment and adaptive functioning (Anderson et al., 2006; Ewing-Cobbs et al., 2004; Ewing-Cobbs et al., 2006; Schwartz et al., 2003; Stancin et al., 2002; Taylor et al., 2002; Yeates et al., 2004).

The negative effects of pediatric TBI, in both cognitive (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2005; Ewing-Cobbs et al., 1997; Verger et al., 2000) and academic (Barnes, Dennis, & Wilkinson, 1999; Catroppa et al., 2009; Ewing-Cobbs et al., 2006) domains, are especially pronounced when injuries occur prior to school age. Pathophysiological susceptibility of the young brain to TBI provides one potential explanation of this vulnerability (Anderson et al., 2005; Bruce, 1995; Freeman et al., 2008; Krier, Krach, & Panser, 1989). Developmental factors are also likely play a role in these vulnerabilities. More specifically, because young children have fewer consolidated skills than older children, they are at risk for neurocognitive difficulties after TBI both because of the loss of previously acquired skills and the failure to develop new abilities. Thus, young children's vulnerability to neurocognitive deficits may extend beyond those witnessed at the time of injury to include deficits that the child 'grows into' over time (Anderson & Moore, 1995). This may be particularly true for academic outcomes, as disruption in early neurocognitive abilities may impede the acquisition of early academic skills, which serve as a foundation for future academic learning (Anderson et al., 2006; Barnes et al., 1999; Catroppa, Anderson, Morse, Haritou, & Rosenfeld, 2008; Ewing-Cobbs et al., 1997, 2004, 2006; Taylor & Alden, 1997). The relationship between age of injury and academic risk is complex, as different academic skills vary in their vulnerability to early insult. For example, in a recent longitudinal study (Catroppa et al., 2009), children injured during the preschool years were more vulnerable to later reading impairments than children injured during school age years. However, age-based differences in the outcomes of TBI did not extend to math or spelling skills.

Despite the general risks associated with TBI in the preschool years, substantial variability in outcomes exists among individual children following injury (Anderson et al., 2005, 2006; Catroppa et al., 2008). Therefore, research has begun to focus on factors that predict individual differences in outcomes following early TBI. Injury severity and family factors are consistent predictors of cognitive and behavioral outcomes (Anderson et al., 1997, 2005, 2006; Catroppa et al., 2008; Ewing-Cobbs et al., 1997; Taylor et al., 2008). These factors are also associated with academic outcomes following early TBI (Anderson et al., 2006; Catroppa et al., 2008, 2009; Ewing-Cobbs et al., 2006).

Cognitive factors account for much of the variance in academic outcomes in children following TBI. For instance, intellectual functioning assessed during acute recovery from TBI predicts later academic achievement in both preschool and school-aged children (Catroppa et al. 2009; Catroppa & Anderson, 1999). This finding is not surprising given the

well recognized relationship between intellectual functioning and academic achievement (Beres, Kaufman, & Perlman, 2000; Goldstein & Hersen, 2000). Specific neurocognitive skills also predict academic outcomes in school-aged children. For instance, Kinsella et al. (1995, 1997) examined the relationship between neuropsychological variables and special education placement in school-aged children following TBI. Logistic regression revealed that verbal memory (i.e., list learning) and verbal fluency were associated with special education placement at 12 and 24 months following injury. A similar finding was noted by Miller and Donders (2003), who found that children with verbal memory difficulties were significantly more likely to be placed in special education 12–24 months following injury than children who obtained higher scores. Catroppa and Anderson (2007) also found that verbal memory skills assessed during acute recovery from TBI correlated with academic variables at 2 years post injury.

Ewing-Cobbs et al. (2004) serially evaluated school-aged children for 5 years following TBI. Their study revealed that concurrent development of specific neurocognitive skills was related to academic achievement. Furthermore, the relationships between specific neurocognitive skills and academic outcomes remained significant once the influence of injury and socioeconomic factors were taken into account. The predictive validity of specific neurocognitive skills was also found to vary across academic outcomes. Nonverbal memory and visual constructional skills were associated with the development of mathematics, whereas word generation and rapid naming skills were associated with reading and spelling outcomes. This finding suggests that individual specific neurocognitive skills may contribute in unique ways to different types of academic skills.

Despite an emerging understanding of the relationships between specific neurocognitive skills and academic outcomes in school-aged children with TBI, similar research with TBI acquired during the preschool years is lacking. This may be due, in part, to the paucity of developmentally-appropriate neurocognitive measures for young children. However, despite this challenge, recent research with typically developing preschool children has demonstrated that specific neurocognitive skills, such as memory and executive functions, are involved in the development of future academic skills (Bull, Espy, & Wiebe, 2008; Clark, Pritchard, & Woodward, 2010; Espy et al., 2004; McClelland et al., 2007; Pritchard & Woodward, 2011). The identification of specific neurocognitive deficits that contribute to academic difficulties following TBI may have particular importance for children injured during the preschool years, given their heightened vulnerability to negative academic outcomes. Research in this regard may assist in identifying those children who are at risk for academic impairments and facilitate prompt delivery of educational assistance for these children, using interventions tailored to accommodating their specific neurocognitive deficits.

Taylor et al. (2008) recently described post-acute cognitive and school readiness skills in young children with TBI. Data were gathered as part of a prospective, longitudinal study conducted at several hospitals. Participants included young children (ages 3–6 years) hospitalized for mild to severe TBI, as well as a comparison group of children of like age hospitalized for orthopedic injuries (OI). Children with OI were chosen as a comparison group to control for risk factors that may have led to the injury and those associated with the experience of being hospitalized. Injury severity predicted intellectual functioning, verbal memory, executive function, and school readiness skills as assessed approximately 1 month following injury.

The primary objective of the present study was to extend the study by Taylor et al. (2008) by examining predictors of academic achievement in young children with TBI and OI shortly after injury and at 1 year post injury. More specifically, we examined the relationships

between post-acute assessments of verbal memory and executive functions, as well as intellectual abilities, with academic achievement assessed concurrently and at 1 year post injury. We hypothesized that verbal memory and executive functions assessed during the post-acute period would be significant predictors of academic achievement evaluated concurrently and at 1-year post injury. We also hypothesized that performance in these domains would account for variance in academic skills, over and above the effects of general intellectual functioning.

METHODS

Design

Data were collected as part of a multi-site, longitudinal investigation of TBI in young children that employed a concurrent cohort/prospective research design, as described elsewhere in greater detail (Chapman et al., 2010; Stancin, Wade, Walz, Yeates, & Taylor, 2008; Taylor et al., 2008; Wade et al., 2008). The study was approved by the Institutional Review Boards at each of the medical centers involved, with informed parental consent and child assent obtained prior to participation.

Participants

Consecutive admissions of children with documented TBI or with OI not involving the head were recruited for the study from three children's hospitals and one general hospital with Level 1 trauma units in the State of Ohio. Participants met the following eligibility requirements: age from 36 to 83 months at the time of injury, no documentation in the medical chart or in parent interview of child abuse as a cause of the injury, and English as the primary spoken language in the home. Children who sustained non-blunt head trauma (e.g., projectile wounds, strokes, near drowning) were excluded from the study. Enrollment in the TBI group required overnight admission to the hospital and evidence of a moderate or severe injury. Consistent with previous studies (Ewing-Cobbs et al., 2004; Fletcher et al., 1990; Taylor et al., 2008), TBI severity was based on the lowest post-resuscitation score on the Glasgow Coma Scale (GCS). Severe TBI was defined as a GCS score of 8 or less and moderate TBI was defined as a score of 9–12 or a higher GCS score with evidence of TBI-related brain abnormalities from computed tomography (CT) or magnetic resonance imaging (MRI). Because the focus of this study was on children with moderate to severe TBI, a small group of children with mild TBI (i.e., GCS > 12 without neuroimaging findings) were not included in the analysis. Children with TBI were included regardless of whether they also experienced OI. Inclusion in the OI group required a documented bone fracture resulting in at least an overnight hospital stay, in the absence of any evidence suggestive of head or brain injury.

The initial sample consisted of 206 children (OI = 119, severe TBI = 23, moderate TBI = 64). Recruitment rates for families who were contacted were somewhat higher for the TBI group as a whole than for the OI group (53% vs. 35%). In both groups, the most common reasons for non-participation were a lack of interest or not having time for the study. Participants and non-participants did not differ on sex, race, age at injury, or census-based estimates of neighborhood income. For the present study, only children with complete academic data from the post-acute and 12-month follow-up assessments were included in the current analysis. Therefore, 63 children were excluded from the analysis, leaving a final sample of 80 children with OI, 17 children with severe TBI, and 46 children with moderate TBI. Children included in the analysis did not differ from those who were excluded in age, race, sex, injury group, socioeconomic status, or time between their injury and the post-acute assessment.

Table 1 presents demographic and injury characteristics for participants by group. Injury groups did not differ in gender, age at injury, or minority status. The groups differed significantly in socioeconomic status (SES), with lower SES noted in the severe TBI group in comparison to the OI group. SES was defined in terms of a composite of maternal education and median income for the census tract in which the family resided; the composite was computed by averaging the sample *z* scores of the two variables. Length of hospital stay was also significantly longer for both TBI groups relative to the OI group. Time between injury and initial assessment was shorter also for the OI group relative to the moderate TBI group. This difference likely reflected our willingness to extend recruitment somewhat beyond the desired window (i.e., 3 months post injury) so as to maximize enrollment of children with TBI. Most of the injuries across participants were secondary to transportation or falls, consistent with national trends for young children (Langlois, Ruthland-Brown, & Thomas, 2006). However, the OI group demonstrated more playground equipment related injuries in comparison to the other groups.

Procedures and Measures

Tests of cognitive and academic skills were administered as part of evaluations of the child and family conducted during the post-acute phase of recovery (around 1 month after injury) and at 12 months post-injury. The order of test administration was fixed, within the context of a larger neuropsychological battery.

Intelligence—The Differential Ability Scales (DAS) was used to assess general intellectual functioning (Elliott, 1990). The DAS is a battery of cognitive tests for ages 2.5 through 17 years. To obtain a measure of general cognitive ability, we administered the core subtests needed to compute the Global Conceptual Ability score (GCA) for the child's age. Internal consistency indexes are .89 or higher across the preschool range and test-retest reliability is .90 over a 4-week interval. Standard scores for age were used in analysis of these and other measures with published norms.

Verbal Memory—Verbal memory was measured using the Story Recall subtest of the Woodcock Johnson Tests of Achievement-Third Edition (WJ-III; McGrew and Woodcock, 2001). During this task, the child hears a series of brief stories and attempts to retell them. Reliability calculated through Rasch analysis procedures ranges from .85 to .87 across the ages of children in the current study.

Executive Function—Tests of executive function included the Shape School and Delayed Alternation tasks. Raw scores were used for these measures, as published norms have not been developed. The Shape School is a Stroop-like measure for preschoolers that has demonstrated satisfactory reliability and validity in previous research (Espy, 1997; Espy, Kaufman, McDiarmid, & Glishy, 1999; Espy, Bull, Martin, & Stroup, 2006). In this task, the child is first taught to name cartoon “pupils” by their shapes or colors. During the Inhibition trial, the child is then asked to name the color of each pupil who is “ready for lunch” (those with smiling faces), while inhibiting naming of each pupil who is “not ready” (those with sad faces). This test measures the ability to inhibit pre-potent responses. The current study used an efficiency score from this trial, which takes into account both speed and accuracy. The choice of the efficiency score from the Inhibition trial is consistent with previous research with typically developing preschool children that documented the predictive value of this task in relationship to the development of reading and math skills (Clark et al., 2010).

In Delayed Alternation, the child is asked to retrieve a reward (e.g., an M&M or a Cheerio) hidden under one of two cups placed side by side. The contingency is then reversed with the reward hidden under the other cup. The child is not allowed to see where the reward is

placed, but can learn to anticipate placement because the placement side is reversed after each correct response. Performance was defined in terms of the longest sequence of consecutive correct responses. The Delayed Alternation task has demonstrated satisfactory reliability and validity (Espy et al., 1999).

Early Academic Skills—To assess early academic skills, children were administered the six subtests comprising the School Readiness Composite (SRC) of the Bracken Basic Concept Scale-Revised (BBCS-R; Bracken, 2006), as well as the Letter/Word Identification, Spelling, and Applied Problems subtests of Woodcock - Johnson Tests of Achievement-Third Edition (WJ-III; McGrew & Woodcock, 2001). Age-adjusted standard scores were used from each academic measure. The SRC assesses recognition of colors, letters, numbers, sizes, and shapes, as well as the ability to make simple conceptual comparisons. The measure does not require verbal responses (e.g., children point to the desired response). Test-retest reliability over an interval ranging from 2–30 days is .92 for younger children (36–59 months) and .76 for older children (60–83 months). The WJ-III subtests measure letter and word recognition, pencil control and written spelling of letters and words, and knowledge of early math concepts. Reliability statistics range between .77 and .99 between the three subtests across the age groups used in the current study, with most above .90.

Statistical Analysis

Analysis of covariance was used to examine group differences on cognitive measures and repeated measures analysis of covariance was used to examine group differences in performance on each of the academic measures over time. SES was treated as a covariate to control for differences between injury groups.

For the main hypotheses of the study, hierarchical linear regression analyses were used to examine the prediction of academic outcomes as a function of demographics, injury group, and cognitive variables. Eight separate analyses were conducted, one for each of the four academic measures at both time points. Predictors were entered in three steps. In the first step, demographic variables were entered, including race (white vs. non-white), age at injury, and family socioeconomic status (SES). Injury group was also entered in this step by creating two dummy variables, the first comparing moderate TBI to OI and the second comparing severe TBI to OI. In the second step, tests of memory and executive function (i.e. WJ-III Story Recall, Shape School inhibition, and Delayed Alternation) obtained during the post-acute evaluation were entered into the model. In the third step, the DAS GCA was entered into the model. Finally, in the fourth step, interaction terms were entered into the analyses to determine if the relationship between cognitive and academic variables varied as a function of group membership (i.e., TBI versus OI).

Following the initial set of regressions, an additional set of analyses was completed to examine the incremental variance accounted for by cognitive predictors after taking into account more specific injury factors. The analyses were completed in the same fashion as the original regressions, but were restricted to children with TBI and used the Glasgow Coma Scale (GCS) score as a measure of injury severity in lieu of the dummy variables for injury group.

An additional 20 children were excluded from both sets of regression analyses due to missing cognitive test data; thus the sample for the regression analyses included 71 children with OI, 39 children with moderate TBI, and 13 children with severe TBI. Indices of multicollinearity were within acceptable ranges for both sets of regression analyses.

RESULTS

Group Differences in Academic Performance

Table 1 summarizes group performances on cognitive measures completed during the post-acute assessment. Significant group differences were noted on the DAS Global Conceptual Ability composite, $F(2, 139) = 6.204$, $p < .01$. The analysis of academic performance, summarized in Table 2, revealed significant group differences on the WJ-III Applied Problems subtest, $F(2, 139) = 3.805$, $p < .05$, and the BBCS-R, $F(2, 139) = 7.563$, $p < .001$. Post hoc analyses revealed that the severe TBI Group displayed significantly lower scores than the OI group on the Applied Problems subtest, $p < .05$, with the difference between the severe and moderate TBI groups approaching significance, $p = .06$. The severe TBI group scored lower than both the moderate TBI group and the OI group on the BBCS-R, both $p < .01$. Across groups, children demonstrated improved performance on the Applied Problems subtest from post acute testing ($M = 102.64$, $SD = 13.53$) to 12-month follow-up ($M = 105.68$, $SD = 12.85$), $F(1, 139) = 4.86$, $p < .05$. Performance also improved on the BBCS-R from the post-acute assessment ($M = 103.15$, $SD = 16.07$) to 12-month follow-up ($M = 105.14$, $SD = 13.58$), $F(1, 139) = 7.854$, $p < .01$. However, group by time interactions were not significant for any of the academic measures.

Prediction of Academic Performance

Table 3 summarizes the results from the hierarchical regression analyses. Collectively, demographic variables and injury group were significant predictors of math and school readiness skills at both time points, as well as reading skills at 12 months post-injury. Examination of individual predictors showed that socioeconomic status accounted for unique variance in math and school readiness skills at both the acute and 12-month follow-up, with higher SES associated with better academic skills. Race accounted for unique variance in school readiness skills at both time points, with non-white children performing more poorly. Age accounted for spelling and math skills at 12-month follow-up, with younger children performing more poorly. Finally, group status accounted for significant variance in math and school readiness skills at both time points, but only for the comparison of the severe TBI and OI groups.

Collectively, memory and executive functions accounted for significant variance in all four academic measures at both time points. Examination of individual predictors revealed that the WJ-III Story Recall subtest accounted for unique variance in math skills at both time points and school readiness skills at 12-month follow-up, with better memory performance predicting better academic skills. The Shape School Inhibition score was uniquely associated with all four academic measures at both time points, again with better inhibitory control predicting better academic skills. The Delayed Alternation task was not a unique predictor of any academic measures at either time point.

In the third step, the DAS GCA significantly predicted all four academic measures at both assessments (post-acute and 12 month follow-up), with higher intellectual functioning predicting better academic skills. When intellectual ability was added to the model, verbal memory no longer accounted for unique variance in any of the academic measures. However, performance on Shape School Inhibition continued to account for unique variance in spelling, reading, and math skills at 12 months post-injury. The final step of the analysis (details omitted from Table 3 but available on request) showed that interactions between group membership and cognitive skills did not account for significant variance in academic outcomes. To consider the potential impact of repeated analyses on the likelihood of committing a Type-I error, the results from regression analyses were considered in light of a Bonferroni correction, requiring a significance level of $p < .00625$ (i.e., .05 divided by

number of regression analyses). Under this stringent standard, the significance of the relationships between Shape School and academic outcomes remains unchanged for all academic outcomes, with the exception of reading during the post-acute assessment. Verbal memory no longer accounted for significant variability in math skills at either time point, but remained significantly related to school readiness skills at 12-months follow-up.

Table 4 summarizes the results from the additional hierarchical regression analyses using only children with TBI and substituting the GCS score as the measure of injury severity. The results were largely consistent with the original analyses. However, performance on Shape School accounted for somewhat less variance than in the main analyses, whereas relationships for DAS GCA were typically stronger. Thus, Shape School did not predict academic outcomes when the DAS GCA was taken into account. Additionally, the Delayed Alternation (DA) task accounted for unique variance in arithmetic and spelling skills at the 12-month follow-up. Better performance on the DA unexpectedly predicted weaker math skills, but better performance in spelling after general intellectual ability was taken into account.

DISCUSSION

The current study is consistent with previous investigations in documenting the negative effects of preschool TBI on academic skill development (Anderson et al., 1997, 2006; Barnes, Dennis, & Wilkinson, 1999; Catroppa et al., 2008, 2009; Ewing-Cobbs et al., 1997, 2006). Children with severe TBI demonstrated weaker development of arithmetic abilities and in school readiness skills. Deficits in school readiness skills were seen more clearly on the BBCS-R than the WJ-III, perhaps because the WJ-III utilizes relatively fewer items for early reading, spelling, and math skills as compared to the BBCS-R.

The findings also indicate that specific post-injury neurocognitive skills of executive functions and verbal memory predict achievement levels following both TBI and OI. Better performance in these domains during the early phase of recovery is associated with better academic skills, assessed concurrently and 1-year following injury. These associations were apparent after taking into account demographic and injury variables. These findings are consistent with previous research with normally developing preschool children in revealing a significant relationship between early development of memory and executive functions and future academic development (Bull et al., 2008; Espy et al., 2004; McClelland et al., 2007). The current findings also extend past research with school-aged children in providing evidence for the role of specific neurocognitive skills following TBI in predicting current and future academic achievement (Ewing-Cobbs et al., 2004; Catroppa and Anderson, 2007; Kinsella et al., 1995, 1997).

Examination of the unique contribution of specific neurocognitive skills revealed that the most consistent relationships were found with one of the measures of executive function (i.e., Shape School Inhibition), which continued to account for variability in academic outcomes at 12-month follow-up after general intellectual functioning was taken into account. This finding is consistent with previous research with typically developing preschool children, in that it suggests a specific association between the ability to inhibit prepotent responses and the development of early academic skills (Clark et al., 2010; Espy et al., 2006). Verbal memory also was uniquely related to math skills at both time points and school readiness skills at 12-month follow-up. This finding is consistent with previous studies that have illustrated a relationship between verbal memory skills and academic outcomes in school-aged children following TBI (Catroppa & Anderson, 2007; Kinsella et al. 1995, 1997; Miller & Donders, 2003). In contrast, performance on the Delayed Alternation task did not uniquely contribute to the prediction of academic outcomes, except

in the additional regression analyses, where it predicted worse math skills and better spelling skills at 12 months. Findings with this task may reflect limited sensitivity of Delayed Alternation to pediatric TBI (Levin et al. 1994; Taylor et al., 2008). When considered together, variations in the relationships between different neurocognitive skills and early academic achievement suggest that these skills likely play unique roles in supporting early academic learning. The nature of the relationships identified in the regression analyses remained consistent over time. In fact, when intellectual functioning was controlled, the unique relationship between Shape School and academic outcomes was actually stronger at the 12-month follow-up.

Although not the main objective of the current study, the findings also confirm previous research by documenting a relationship between intellectual functioning in preschool children following TBI and later academic achievement (Catroppa et al., 2009). Additionally, the results are in accord with past research in showing that demographic variables (i.e. SES and race) also are associated with school readiness and academic skills (Anderson et al., 2006; Taylor et al. 2008).

The current study should be considered in the context of several limitations. Academic development was assessed over a limited time span (i.e., 12 months) and at only two time points. Thus, the current study does not address the relationship between early neurocognitive skills and academic achievement throughout childhood. Additionally, limitations in the availability of measures of memory and executive functions in young children likely hampered the study. Memory skills were evaluated using a single measure that involved narrative recall, as opposed to multiple measures that provide a composite index. In particular, the lack of list learning tasks for this age group is a shortcoming, given the previously documented relationship between performance on such measures and academic outcomes (Kinsella et al., 1995, 1997; Miller & Donders, 2003). The limited availability of measures of executive functions in young children was also problematic. Although the Shape School was designed for young children, a significant number of participants from the original study were excluded due to missing data on this task, which appeared to prove too challenging for many of the younger children in the study, in both the TBI and OI groups. Finally, the assessment of the severity of TBI was limited and did not include more detailed measures of neuropathology (e.g., lesion analysis based on neuroimaging). Additional regression analyses showed that the unique variance in academic achievement accounted for by the Shape School task was reduced somewhat when the GCS score was used as a measure of injury severity. Thus, the inclusion of additional markers of injury severity would be beneficial in future studies of early TBI.

Despite these limitations, the current study contributes to our understanding of the relationships between specific cognitive skills and academic outcomes in preschool children following TBI. The study has several clinical implications. To begin with, the findings provide initial support for the utility of measures of verbal memory and executive function in predicting which children are at risk for difficulties with academic achievement following early TBI. Therefore, further refinement of these measures for clinical use may prove beneficial in answering need for neurocognitive measures for use with preschool children (Pritchard & Woodward, 2011). Ultimately, the findings may contribute to the development of specific academic interventions designed to mitigate the negative impact of TBI on later academic development.

The current study also suggests avenues for future research. Studies examining the relationships between other specific cognitive skills and academic outcomes following TBI in preschool children would be beneficial. More specifically, investigations of visual-constructional skills and nonverbal memory are indicated given previous findings linking

these skills to academic outcomes in school aged children following TBI (Ewing-Cobbs et al., 2004). Additionally, longitudinal studies of preschool children following TBI will be beneficial in examining the role of early cognitive outcomes in the long-term development of future academic skills.

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Table 1

Group demographic characteristics and cognitive outcomes

	Group		
	Severe TBI (n = 17)	Moderate TBI (n = 46)	OI (n = 80)
Age at injury in years, M (SD)	4.8 (.9)	5 (1.2)	5.1 (1.1)
Males, n (%)	12 (71%)	26 (57%)	41 (51%)
Minority status (non-white), n (%)	6 (35%)	14 (30%)	15 (19%)
Socioeconomic status ^a , M (SD) *	-.56 (.59)	.01 (1.07)	.29 (.93)
Time since injury to initial assessment in days, mean (SD) *	41.65 (4.5)	44.96 (2.75)	34.75 (2.09)
Length of hospital stay in days, mean (SD) *	5.95 (7.33)	2.47 (1.61)	1.43 (1.19)
Cause of injury, n (%): *			
Transportation	10 (59%)	16 (35%)	13 (16%)
Fall	5 (29%)	23 (50%)	27 (34%)
Sports and recreation	0 (0%)	2 (4%)	9 (11%)
Playground equipment	1 (6%)	2 (4%)	26 (33%)
Rough housing	0 (0%)	2 (4%)	4 (5%)
Falling objects	1 (6%)	1 (2%)	1 (1%)
DAS Global Conceptual Ability ^b (SD) *	83.65 (16.02)	99.93 (16.01)	103.18 (14.79)
WJ-III Story Recall ^b (SD)	101.79 (15.14)	109.36 (14.85)	114.54 (12.57)
Shape School-Inhibition ^c (SD)	.57 (.49)	.74 (.50)	.84 (.53)
Delayed Alternation ^c (SD)	6.35 (4.6)	7.41 (4.99)	7.32 (4.9)

Note: TBI = traumatic brain injury; OI = orthopedic injury; SD = standard deviation; DAS = Differential Ability Scales; WJ-III = Woodcock Johnson Tests of Achievement-Third Edition.

^aSocioeconomic status was assessed by averaging sample z-scores for maternal education and median census tract income.

^bValues on the GCA and WJ-III represent standard scores.

^cValues on the Shape School Inhibition and Delayed Alternation represent raw scores.

* Significant difference, $p < .05$.

Table 2

Academic performance by group

	Severe TBI (n = 17)		Moderate TBI (n = 46)		OI (n = 80)	
	Acute M (SD)	12 months M (SD)	Acute M (SD)	12 months M (SD)	Acute M (SD)	12 months M (SD)
WJ-III Letter/Word Identification	100.82 (14.07)	98.65 (15.82)	105.39 (14.89)	104.09 (11.53)	105.95 (16.02)	108.61 (12.17)
WJ-III Spelling	94.47 (10.93)	91.65 (15.76)	98.89 (12.8)	98.72 (12.18)	99.20 (13.56)	102.77 (12.91)
WJ-III Applied Problems ^a	93.18 (13.18)	95.88 (13.97)	103.41 (13.13)	104.93 (10.87)	104.2 (13.16)	108.19 (12.76)
Bracken SRC ^b	86.71 (13.96)	93.12 (16.44)	102.43 (16.00)	104.89 (12.66)	107.05 (14.32)	107.84 (12.12)

Note: WJ-III = Woodcock Johnson Tests of Achievement-Third Edition, SRC = School Readiness Composite.

^aSignificant difference, severe TBI < OI.^bSignificant difference, severe TBI < moderate TBI and OI.

Table 3

Summary of regression analyses

Predictors	Acute					12 Months				
	Reading	Spelling	Math	SRC		Reading	Spelling	Math	SRC	
Step 1. β										
Socioeconomic Status	.14	.12	.28**	.36**		.10	.01	.30**	.34**	
Race	.05	.02	.13	.17*		.17	.13	.08	.18*	
Age at Injury	-.06	.13	-.06	.02		-.02	.23**	.18*	.02	
Severe TBI vs. OI	-.10	.03	-.18*	-.24**		-.11	-.08	-.19*	-.23**	
Moderate TBI vs. OI	-.03	.04	.07	.01		-.13	-.11	-.04	.02	
Adjusted R ² for step 1	.01	-.01	.16**	.29**		.06*	.05	.17**	.27**	
Step 2. β										
Socioeconomic Status	.06	.04	.16	.27**		.02	-.07	.18**	.23**	
Race	.01	-.04	.08	.13		.10	.05	.03	.12	
Age at Injury	-.21	-.11	-.26*	-.16		-.29*	-.07	-.06	-.18	
Severe TBI vs. OI	-.06	.01	-.11	-.19**		-.09	-.05	-.13	-.17*	
Moderate TBI vs. OI	.05	.06	.11	.04		-.11	.09	.01	.06	
Story Recall	.14	.09	.23**	.15		.02	.06	.19*	.24**	
Shape School Inhibition	.26*	.40**	.35**	.33**		.46**	.44**	.42**	.28**	
Delayed Alternation	-.06	-.03	-.12	-.12		-.04	.04	-.12	.01	
ΔR^2 for step 2	.07*	.11**	.15**	.11**		.13**	.12**	.17**	.10**	
Step 3. β										
Socioeconomic Status	-.13	-.11	.02	.09		-.10	.21*	.06	.10	
Race	-.08	-.12	.01	.05		.05	-.02	-.03	.05	
Age at Injury	-.15	-.06	-.21*	-.10		-.25*	-.02	-.02	-.13	
Severe TBI vs. OI	.01	.06	-.06	-.13*		-.05	.01	-.08	-.11	
Moderate TBI vs. OI	-.01	.01	.06	-.02		-.15	-.13	-.04	.01	
Story Recall	-.02	-.05	.11	-.01		-.08	-.06	.09	.12	

Predictors	Acute				12 Months			
	Reading	Spelling	Math	SRC	Reading	Spelling	Math	SRC
Shape School Inhibition	.01	.19	.15	.09	.30**	.25**	.26**	.09
Delayed Alternation	.03	.04	-.06	-.04	.01	.11	-.07	.08
DAS GCA	.67**	.55**	.51**	.64**	.42**	.50**	.43**	.51**
ΔR^2 for step 3	.22**	.15**	.13**	.21**	.09**	.13**	.09**	.13**

Note: DAS GCA = Differential Ability Scales Global Conceptual Ability standard score; SRC = School Readiness Composite. Sample sizes = 13 severe TBI, 39 moderate TBI, & 71 OI. β represents standardized regression coefficients.

*
p<.05

**
p<.01

Table 4

Summary of regression analyses using only children with TBI and GCS as predictor

Predictors	Acute						12 Months					
	Reading	Spelling	Math	SRC	Reading	Math	Spelling	Math	SRC	Reading	Math	SRC
Step 1. β												
Socioeconomic Status	.04	-.08	.36**	.36**	.03	.28	.05	.28	.32*			
Race	.29	.26	.14	.25	.26	.12	.21	.12	.23			
Lowest GCS score	.09	.03	.27*	.27*	.11	.24	.13	.24	.29*			
Age at Injury	-.14	.05	.05	.10	.07	.25	.21	.25	.18			
Adjusted R ² for step 1	.07	-.02	.25**	.34**	.02	.17*	.03	.17*	.31**			
Step 2. β												
Socioeconomic Status	-.02	-.18	.20	.27	-.06	.10	-.05	.10	.19			
Race	.28	.22	.07	.21	.19	.03	.06	.03	.11			
Lowest GCS score	.06	-.01	.20	.23	.07	.16	.09	.16	.24*			
Age at Injury	-.23	-.07	-.18	-.09	-.17	.0	-.17	.0	-.13			
Story Recall	.01	.16	.21	.04	.03	.25	.1	.25	.20			
Shape School Inhibition	.19	.19	.34*	.31	.35	.36*	.36	.36*	.33*			
Delayed Alternation	-.10	-.07	-.10	-.06	.00	-.07*	.29	-.07*	.12			
ΔR^2 for step 2	.03	.05	.13*	.06	.06	.14*	.13	.14*	.10			
Step 3. β												
Socioeconomic Status	-.18	-.32	.10	.13	-.17	-.01	-.14	-.01	.09			
Race	.11	.07	-.04	.06	.08	-.08	-.04	-.08	.01			
Lowest GCS score	-.14	-.19	.07	.05	-.07	.03	-.03	.03	.11			
Age at Injury	-.09	.05	-.09	.03	-.08	.09	-.09	.09	-.04			
Story Recall	-.17	.01	.1	-.12	-.09	.14	-.01	.14	-.09			
Shape School Inhibition	-.15	-.11	.13	.01	.12	.14	.15	.14	.11			
Delayed Alternation	.02	.04	-.02	.05	.08	.01	.36**	.01	.2			
DAS GCA	.85**	.74**	.54**	.74**	.57**	.56**	.51**	.56**	.54**			

Predictors	Acute				12 Months			
	Reading	Spelling	Math	SRC	Reading	Spelling	Math	SRC
ΔR^2 for step 3	.28**	.21**	.12**	.22**	.13**	.10**	.12**	.12**

Note: GCS = Glasgow Coma Scale; DAS GCA = Differential Ability Scales Global Conceptual Ability standard score; SRC = School Readiness Composite. Sample sizes for analyses = 13 severe TBI, 39 moderate TBI.

* p<.05
** p<.01