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# Predicting Longitudinal Patterns of Functional Deficits in Children with Traumatic Brain Injury

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## Abstract

Longitudinal patterns of functional deficits were investigated in 37 children with severe traumatic brain injuries (TBI), 40 children with moderate TBI, and 44 children with orthopedic injuries (OI). They were from 6 to 12 years of age when injured. Their neuropsychological, behavioral, adaptive, and academic functioning was assessed at 6 months, 12 months, and 3-5 years post injury. Functional deficits (<10th percentile for age) were identified within each outcome domain at each occasion. Children were classified into four *a priori* longitudinal patterns of outcomes within domains (i.e., no deficits, improvement, deterioration, persistent deficits). In multinomial logistic regression analyses, severe TBI predicted an increased likelihood of persistent deficits in all outcome domains, as well as deterioration in behavioral functioning and improvement in neuropsychological, adaptive, and academic functioning. Severe TBI also predicted a greater total number of functional deficits across domains at each occasion. However, many children with severe TBI showed no deficits from 6 months to 4 years post injury in one or more outcome domains. The findings help to clarify the course of recovery for individual children following TBI.

### Keywords

Traumatic brain injury; children; functional deficits; outcomes

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## Predicting Longitudinal Patterns of Functional Deficits in Children with Traumatic Brain Injury

Childhood traumatic brain injury (TBI) is associated with a variety of cognitive, behavioral, adaptive, and academic performance deficits in school-age children. Numerous studies have established persistent neuropsychological sequelae, higher incidences of post-injury psychiatric, emotional, and behavioral problems, difficulties in adaptive functioning, and academic performance deficits after moderate to severe TBI in children (Anderson et al., 2005; Fay et al., 1994; Fletcher et al., 1990; Jaffe et al., 1995; Kinsella et al., 1995; Max et al., 1997; Schwartz et al., 2003; Taylor et al., 1999, 2002; Yeates et al., 2001, 2002; Yeates & Taylor, 2006).

As a group, children with TBI show distinct longitudinal patterns of change in cognitive, academic, behavioral, and adaptive domains. Children with moderate to severe TBI generally show significant improvement in their neuropsychological functioning during the first year post injury, yet recovery often begins to plateau after the first year post injury, with negligible rates of change appearing during the following 2 years post injury (Chadwick et al., 1981; Jaffe et al., 1995). Persistent neuropsychological sequelae of childhood TBI continuing past 1 year post injury have also been documented (Chadwick et al., 1981; Jaffe et al., 1995; Kinsella et al., 1995; Yeates et al., 2002).

Because recovery is a developmental process that occurs over time, new impairments may also emerge (Anderson et al., 1997; Dennis et al., 1995). Long-term follow-up of children with severe TBI suggests that behavioral, adaptive, and academic deficits often fail to resolve over time, despite partial recovery in cognitive functions during the first year (Anderson et al., 2005; Jaffe et al., 1995; Kinsella et al., 1999; Perrot et al., 1991; Schwartz et al., 2003; Taylor et al., 1999, 2002; Yeates et al., 2002). Many studies have found evidence of deterioration in behavioral adjustment across time and persistent post injury behavior problems in children with TBI (Jaffe et al., 1995; Schwartz et al., 2003; Taylor et al., 1999, 2001). Adaptive functioning also may decline during the first year post injury, particularly in the domain of socialization (Anderson et al., 1997; Stancin et al., 2002). Yeates et al. (2001) demonstrated that while cognitive and somatic symptoms declined during the first year post injury in children with TBI, emotional and behavioral symptoms became more common. In addition, a number of studies have demonstrated that initial improvements in academic skills may be most prominent in children with severe TBI, with persisting or worsening functional deficits emerging at later time points (Barry et al., 1996; Ewing-Cobbs et al., 1998; Jaffe et al., 1995; Max et al., 1997).

Almost all previous studies on the outcomes of TBI have compared children with TBI to those with injuries not involving the head or healthy children by testing the statistical significance of mean differences between groups, rather than by examining the presence of functional deficits in individual children. Very few studies have reported the proportion of individual children who display significant functional deficits in specific outcome domains after TBI. The few studies that have explored individual functional deficits in childhood TBI have focused on behavioral and academic impairments. For example, Max et al. (1997) found that by the second year post injury, 36% of children with moderate to severe TBI met criteria for a new psychiatric disorder. Schwartz et al. (2003) found higher rates of clinically significant behavior problems at 3 years post injury in children with moderate to severe TBI than in children with orthopedic injuries. Similarly, Anderson et al. (2005) found that the percentage of moderate to severe behavioral impairment in children with severe TBI increased from 4.8% immediately post-injury to 34.6% by 30 months post-injury. Ewing-Cobbs et al. (1998) examined school performance in children with severe TBI and found that 79% of the cohort had either repeated a grade or were receiving special assistance in school by a two-year postinjury follow-up. In

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addition, Taylor et al. (2003) investigated the rates of placement in special education programs following TBI and found that half of the severe TBI group were in special education programs several years post injury.

In the current study, we investigated longitudinal patterns of functional deficits in children with moderate to severe TBI as compared to children with OI. Our study differs from most previous research by focusing on individual children's performance across the broad array of domains that are often examined by neuropsychologists in clinical practice, including behavioral and adaptive functioning and academic and neuropsychological performance. Moreover, we did not examine the statistical significance of group differences in means between children with TBI and orthopedic injuries (OI) using a variable-centered approach, as past research has done almost exclusively; instead, we adopted a person-centered approach and studied patterns of functional deficits over time in individual children. Person- and variable-centered approaches are associated with complementary analytic methods that conceptualize the organization of longitudinal data differently. Both approaches contribute to the understanding of specific links between predictors and outcomes, relations between individual positions on latent dimensions, and patterns of individual development across time (Laursen & Hoff, 2006; Magnusson, 2003; Bergman & Trost, 2006; von Eye & Bogat, 2006).

For our purposes, we identified individual patterns of functional deficits across time by choosing a cutoff score. The use of a cutoff score was necessary to classify each child's performance in terms of whether or not it represented a deficit that was atypical from a normative perspective, and hence likely to be apparent in 'real world' functioning. No universal agreement exists regarding the definition of functional deficits or clinically-relevant impairments. Furthermore, cutoff scores unavoidably impose an arbitrary group structure on continuous distributions (Francis et al., 2005). However, scores that fall below the tenth percentile (i.e., $\leq -1.3$ standard deviations) are often considered to represent significant impairment or deficits in clinical neuropsychological practice (Hannay & Lezak, 2004; Golden et al., 1991; Heaton et al., 1991). We thus defined a functional deficit in this manner for the neuropsychological, academic, and adaptive domains, and in a similar manner for the behavior domain (i.e., $\geq +1.3$ standard deviations). We then classified children into four a priori longitudinal patterns of outcomes within each domain: no deficits, persistent deficits, improvement (initial deficit followed by no deficit), and deterioration (no initial deficit followed by later deficit).

Based on previous research, we hypothesized that injury severity would be a predictor of persistent individual deficits in all domains (Anderson et al., 1997, 2005; Fay et al., 1994; Jaffe et al., 1995; Taylor et al., 1999). Because previous literature has shown declines in behavioral functioning, we also hypothesized that children with moderate to severe TBI would be more likely to demonstrate deterioration in behavioral functioning across time than children in the OI group (Anderson et al., 2005; Max et al., 1997; Taylor et al., 2002; Yeates et al., 2001). Finally, in accordance with previous research (Jaffe et al., 1995; Taylor et al., 2002), we expected that improvements in neuropsychological and academic functioning would be more common among children with severe TBI than those with OI.

## Method

### Study Design and Procedures

The study used a concurrent cohort-prospective design in which children 6 to 12 years of age were followed for approximately 3 to 5 years post injury. The total sample included 109 children with TBI and 80 children with orthopedic injuries (OI) recruited from admissions to four hospitals in North-Central Ohio between 1992 and 1995. Children who were admitted to the hospital with a moderate to severe TBI or OI and who met criteria for inclusion were

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contacted prospectively by the study coordinator at each site. An initial assessment was completed on average 3 weeks post injury (mean interval 3.1 weeks, SD = 1.5). Children with TBI had to demonstrate recovery from post-traumatic amnesia prior to any testing; only one child was excluded because of persistent post-traumatic amnesia that did not resolve within the necessary time frame, and that child was not testable because of a persistent vegetative state. Estimates of childhood pre-injury behavioral and adaptive functioning and pre-injury family functioning were obtained for both groups, based on retrospective parent ratings collected during or shortly after hospitalization. Child and family outcomes were assessed 6 and 12 months after the initial evaluation, and again at an extended follow-up on average 4 years post injury (M = 4.16, SD = 0.91). Data included in this study were obtained in compliance with the appropriate Institutional Review Boards.

### Research Participants

Recruitment occurred after informed consent was obtained from the child's parent or guardian. Participants were required to (a) be between 6 and 12 years of age at time of the injury, (b) reside in an English speaking household, (c) be hospitalized for at least one night's duration for either TBI or OI, and (d) have no evidence of child abuse or previous neurological disorder. Children with TBI whose injuries did not fall into the general category of closed head injuries were excluded (e.g., brain injury due to near drowning or toxic exposure, projectile wounds, or stroke).

As reported previously (Taylor et al., 2002; Yeates et al., 2002), children with TBI were classified into two severity groups. Severe TBI was defined on the basis of the lowest Glasgow Coma Scale (GCS) score of 8 or less (Teasdale and Jennett, 1974). Moderate TBI was defined in terms of a GCS score of 9-12 or a score greater than 12 accompanied by complications (i.e., skull fracture, intracranial mass lesion or contusion, diffuse cerebral swelling, post-traumatic neurological abnormality, or documented loss of consciousness greater than 15 minutes). Although many children in the TBI group had accompanying orthopedic injuries, the OI group was limited to children without any symptoms suggestive of a possible central nervous system insult (e.g., symptoms of concussion). Children with OI were chosen as a comparison group to control for the effects of hospitalization as well as for premorbid characteristics that could increase the risk of non-intentional injury. The severity of traumatic injuries that were sustained by children in both groups was assessed using the Injury Severity Scale (ISS) (Mayer et al., 1980; Taylor et al., 1999). The ISS is an anatomical scoring system that provides an overall score for patients with multiple injuries. Each injury is assigned an Abbreviated Injury Scale (AIS) score and is allocated to one of six body regions, including the head. Only the highest AIS score for each body region is used. The scores for the three most severely injured body regions are squared and summed together to produce the ISS score.

For the purposes of the current analysis, we included only children who completed all follow-up assessments (6 months, 1 year, and 4 years post injury). No significant differences were observed in age, gender, race, family composition, or severity of injury when comparing children with TBI who returned for follow-up testing to those that did not. However, families of children with TBI who did not return demonstrated a lower socioeconomic status. Among children with OI, no significant differences in demographic characteristics were found between those who returned for follow-up testing and those who did not. The final sample consisted of 37 children with severe TBI, 40 with moderate TBI, and 44 children with OI.

Table 1 summarizes the demographics characteristics of the three groups, which did not differ in age at injury, gender, family composition, socioeconomic status, or time from injury to the 4 year follow-up testing. Children from the OI group were more likely to be of African American ethnicity $\chi^2$ (1, $N$ = 121) = 5.97. In addition, and as expected, the groups differed significantly in duration of hospitalization ($p < .05$) and ISS ($p < .01$), with the severe TBI

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group demonstrating the longest hospitalization stay and most severe injuries. The moderate TBI group had a somewhat higher mean GCS score than might be expected, but included children who in some studies would be classified as complicated mild TBI (i.e., GCS 13-15 but with extended loss of consciousness or abnormal neuroimaging).

## Measures

**Family functioning—**Family measures included parent ratings of premorbid family functioning and non-injury-related environmental stress, obtained at the baseline assessment, as well as a composite measure of socioeconomic status. The 12-item General Functioning Scale from the McMaster Family Assessment Device was used as a summary measure of family functioning (FAD; Miller, et al., 1985; Stevenson-Hinde & Akister, 1995). Environmental stress unrelated to the injury was measured using a composite derived from the Life Stressors and Social Resources Inventory-Adult Form (LISRES-A; Moos & Moos, 1994). The composite was an average of T scores for all stress subscales aside from those specific to the child and to negative life events. Potential effects of the original injury on the latter two subscales justified their exclusion. A Socioeconomic Composite Index (SCI) was computed to provide a distal measure of the family environment (Yeates & Taylor, 1997). It was computed by averaging sample z scores for the Duncan Occupational Status Index (Stevens & Featherman, 1981), annual family income as coded on the LISRES-A, and years of maternal education as measured at the baseline assessment.

**Neuropsychological functioning—**Children were administered a set of neuropsychological tests (see Yeates et al., 2002 for details). The tests included a short form of the Wechsler Intelligence Scale for Children, Third Edition (WISC-III; Wechsler, 1991), which provided prorated Verbal and Performance IQ scores; Recalling Sentences subtest of the Clinical Evaluation of Language Fundamentals-Revised (CELF-R; Semel et al., 1987); Developmental Test of Visual-Motor Integration (VMI; Beery, 1989); Contingency Naming Test (Taylor et al., 1998; Anderson et al., 2000), Boston Naming Test (Yeates, 1994); Controlled Oral Word Association Test (COWA; Spreen & Strauss, 1991); a prepublication version of the California Verbal Learning Test (CVLT; Delis et al., 1986); Continuous Performance Test-3 (CPT-3; Lindgren & Lyons, 1984); Subtests 2, 4, and 9 of the Underlining Test (Rourke & Orr, 1977); and Grooved Pegboard Test (Knights & Norwood, 1980). All tests were completed at each assessment, with the exception of the Grooved Pegboard, which was administered only at the 6 and 12 month assessments.

A poor neuropsychological outcome was defined based on the presence of three or more functional deficits (i.e., age-based standardized scores below the $10^{th}$ percentile) at each assessment. Age-corrected standard scores were used in coding tests with published norms. For tests without published norms, raw scores were transformed to age and gender-corrected z scores prior to analysis (Taylor & Schatschneider, 1992). Transformations were based on the performances of the OI group at each assessment. Eleven neuropsychological tests were administered in total; the cutoff of three or more functional deficits minimizes the likelihood of false positives when identifying a poor neuropsychological outcome at each assessment (Ingraham & Aiken, 1996).

**Behavioral functioning—**Behavioral functioning was assessed by having parents complete the Child Behavior Checklist (CBCL; Achenbach, 1991), a widely-used rating scale with good reliability and validity. A functional deficit in behavioral adjustment was defined as a Total Behavior Problem T-Score above the $90^{th}$ percentile.

**Adaptive functioning—**Adaptive functioning was assessed using the Vineland Adaptive Behavior Scales, which is a semi-structured parent interview (VABS; Sparrow et al., 1984). A

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functional deficit in adaptive behavior was defined as one or more age-based standard scores below the 10th percentile on the Communication, Daily Living Skills, or Socialization scales.

**Academic outcome—**Children completed the Word Identification, Writing Sample, and Calculation subtests of the Woodcock-Johnson Test of Achievement- Revised (WJ-R; Woodcock & Mather, 1989). A functional deficit in academic skills was defined as one or more age-based standard scores below the 10th percentile.

## Data Analysis

Each individual child's outcomes at each occasion within each domain (i.e., neuropsychological, behavioral, adaptive and academic) were coded into dichotomous dependent variables (i.e., functional deficit versus no deficit) using the criteria described above. We then examined patterns of outcomes in each domain across time. Children were classified into four a priori longitudinal patterns of outcomes within domains: no deficit at any occasion; persistent deficits at all occasions; improvement (i.e., deficit at 6 months followed by no deficit at 1 and 4 years or deficits at 6 months and 1 year followed by no deficit at 4 years); and deterioration (i.e., no deficit at 6 months followed by deficits at both 1 and 4 years post-injury or no deficits at 6 months or 1 year followed by deficit at 4 years post-injury). The classification represents a person-centered approach to outcome assessment in high-risk groups (Laursen & Hoff, 2006; Connell et al., 2006; Masten, 2001), focusing on patterns of outcome suggested by previous longitudinal studies of children with TBI (Taylor, 2004).

Multinomial logistic regression was used to compare the TBI and OI groups in terms of the frequency of different patterns of post-injury functional deficits for each of the four types of outcomes. The analyses included two dummy variables that represented contrasts between the severe TBI and OI groups and between the moderate TBI and OI groups. Predictors used as covariates included ethnicity (white vs. non-white), socioeconomic status (SCI), pre-injury family functioning (FAD General Functioning) and environmental stress (LISRES-A), child pre-injury child behavioral adjustment and school performance (CBCL Total Problems T score & school competence T score), and pre-injury child adaptive functioning (baseline VABS Adaptive Behavior Composite standard score). Preinjury child status was thus assessed using multiple indicators. The dependent variable in each analysis was the pattern of outcome, using “no deficits” as the reference category.

To identify indices of TBI severity associated with patterns of functional deficits over the follow-up interval, separate multinomial logistic regression analyses for each functional outcome were conducted for the TBI sample only. Instead of dummy variables representing group membership, the lowest post-resuscitation GCS score and duration of impaired consciousness were used as indices of severity of injury. Because the two indices are highly correlated, analyses including both indices would not converge or were characterized by singularities; therefore, separate multinomial logistic regression analyses were conducted for each measure of severity. The other predictors remained largely the same as the group comparisons, although environmental stress (LISRES-A) was eliminated from the analyses because some analyses would not converge to a solution when it was included. The reference category for each dependent variable again was “no deficits”.

A variable number of children showed patterns of functional deficits that could not be classified into the four major categories, and were excluded from the respective multinomial logistic regression analysis. Seven children were excluded in the neuropsychological domain (one severe TBI, three moderate TBI, three OI), nine in the behavioral domain (one severe TBI, four moderate TBI, four OI), four in the academic domain (one severe TBI, one moderate TBI, two OI), and 13 in the adaptive domain (six severe TBI, five moderate, two OI). The children

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excluded from one analysis were not always the same as those excluded from any other. The total number of participants reported in Table 1 includes all cases.

To examine the co-morbidity of functional deficits, ordinal regression analyses were conducted on the total number of functional deficits (range = 0-4) at each of the follow-up assessments. Similar to the multinomial regression analysis, the ordinal regression analyses were conducted with the same dummy variables representing group contrasts and the same covariates. Additionally, separate ordinal regression analyses were conducted on the TBI sample only with GCS score and duration of impaired consciousness used as indices of injury severity. The ordinal regression analyses included all children.

## Results

### Group Differences in Functional Deficits

Table 2 presents the number and percentage of children from each group who displayed the four longitudinal patterns of outcome within each domain. In the multinomial logistic regression analyses, the addition of the severe TBI and OI group contrast contributed to improved model fit in all four outcome domains (see Table 3), all $\chi^2$ s > 8.13, and all $p < .05$. As Table 2 shows, the severe TBI group was more likely than the OI group to display persistent deficits in all four outcome domains (i.e., 17-23% vs. 3-7%, depending on domain). In addition, the severe TBI group was more likely than the OI group to display a pattern of deterioration in behavioral outcomes (19% vs. 5%). Notably, Table 2 also shows that between 48% and 67% of the severe TBI group showed no functional deficits in neuropsychological, behavioral, academic or adaptive functioning over time.

The addition of the moderate TBI and OI group contrast also contributed to improved model fit for the neuropsychological and academic outcomes, $\chi^2$s > 7.90, $p < .05$ (see Table 3). The moderate TBI group was significantly more likely than the OI group to display persistent neuropsychological deficits (14% vs. 5%; see Table 2). None of the specific patterns involving adaptive or academic outcomes was significantly more common among the moderate TBI group.

Children's premorbid functioning was also a consistent predictor of outcome. Premorbid adaptive functioning significantly predicted neuropsychological, behavioral, adaptive and academic outcomes, all $\chi^2$ s > 8.34 and all $p < .05$, premorbid behavioral functioning significantly predicted behavioral and adaptive outcomes, both $\chi^2$ s > 13.59 and both $p < .05$, and premorbid school functioning significantly predicted academic outcomes, $\chi^2 = 22.79$ and $p < .01$. In general, poorer premorbid functioning predicted an increased likelihood of persistent deficits (see Table 3). Poorer premorbid functioning also predicted an increased likelihood of improvement in some domains, although poor premorbid school performance predicted an increased likelihood of deterioration in academic outcomes.

Environmental factors at baseline also predicted outcomes in multiple domains. Socioeconomic status predicted neuropsychological, behavioral and academic outcomes, both $\chi^2$ s > 18.78 and all $p < .01$, and family environmental stress (i.e., LESRI) predicted academic outcomes, $\chi^2 = 8.59$ and $p < .05$. In general, lower socioeconomic status was associated with increased likelihood of persistent deficits, and lower family stress predicted an increased likelihood of improvement in academic functioning (see Table 3).

Table 4 shows the number and percentage of children from each group who displayed from 0 to 4 total deficits across domains at each occasion. The groups differed significantly in the total number of total functional deficits. The models that included the contrast between the severe TBI and OI groups demonstrated a significantly better overall fit than models without that

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contrast at all three time periods (all Wald statistics >8.36, and all $p< .05$ ). As Table 4 shows, children in the severe TBI group were more likely than those in the OI group to display 3 or more functional deficits at all time periods, depending on the time post injury (i.e., 16-25% vs. 2-12%).

Models that included the contrasts between the moderate TBI and OI groups resulted in a significantly better overall fit than models without that contrast at only 1 year post injury (Wald statistic =6.92, $p< .05$; see Table 4). Children in the moderate TBI group were more likely than those in the OI group to display more total deficits (13% displayed 3 or more total deficits vs. 2% of the OI group).

### Indices of TBI Severity as Predictors of Functional Deficits

Table 5 summarizes the results of the multinomial regression analyses using duration of unconsciousness to predict the four longitudinal patterns of outcome within each domain. Models that included duration of unconsciousness as a predictor demonstrated a significantly better overall fit than models without that predictor for neuropsychological, adaptive, and academic outcomes, $\chi^2 > 8.41$, $p < .05$. A longer duration of unconsciousness was associated with a greater likelihood of persistent neuropsychological and adaptive deficits, as well as with a greater likelihood of improvement in neuropsychological, adaptive, and academic outcomes.

Table 6 summarizes the results of the multinomial regression analyses using lowest GCS score to predict the four longitudinal patterns of outcome within each domain. Inclusion of the lowest GCS as a predictor yielded a significantly better overall fit than when that predictor was excluded for behavioral, adaptive, and academic outcomes, $\chi^2 > 8.14$, $p < .05$. A lower GCS score was associated with a greater likelihood of persistent adaptive deficits and improvement in adaptive outcome, as well as with a greater likelihood of deterioration in behavioral outcomes.

When examining the TBI group only, children's premorbid functioning remained a consistent predictor of outcome. Premorbid behavioral functioning significantly predicted behavioral, adaptive, and academic outcomes, all $\chi^2$ s > 9.13, and all $p < .05$, and premorbid school performance significantly predicted neuropsychological, behavioral, and academic functioning, all $\chi^2$ s > 10.91, and all $p < .05$ (see Tables 5 & 6). More behavioral problems at baseline were associated with persistent deficits and deterioration in behavioral and adaptive domains, and improvement in adaptive and academic domains. Poorer premorbid school performance was associated with an increased likelihood of deterioration in academic functioning. Environmental variables were less consistently associated with outcomes in the TBI group, but lower socioeconomic status predicted persistent deficits in all outcome domains, all $\chi^2$ s > 9.64, and all $p < .05$, as well as deterioration in behavioral and academic functioning (see Tables 5 & 6).

Duration of unconsciousness and lowest GCS score were also significant predictors of the number of functional deficits at each follow-up occasion. Models that included duration of unconsciousness and lowest GCS score as predictors of the total number of deficits at each occasion demonstrated a significantly better overall fit than models without these predictors, such that greater injury severity was consistently associated with a higher total number of functional deficits (all Wald statistics >4.59, and all $p< .05$ ).

## Discussion

By focusing on individual functional deficits, the current findings help to clarify the nature of the course of recovery after pediatric TBI. The findings support our central hypothesis that children with severe TBI are more likely to demonstrate persistent functional deficits in

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neuropsychological, behavioral, adaptive and academic outcomes than children with OI. On the other hand, many children with severe TBI showed no deficits from 6 months to 4 years post injury in one or more outcome domains. The apparent absence of deficits for these children does not prove that they had no deficits, as many may have been more adversely affected prior to the 6-month follow-up or may have sustained sequelae that were too mild to meet our criteria for functional deficits. Moreover, the severe TBI group displayed significantly more total deficits at all time periods as compared to the OI group. At 1 year post injury, nearly 60% of the severe TBI groups showed functional deficits in at least one domain, as opposed to about 25% of the OI group. Similarly, at 4 years post-injury, about 40% of the severe TBI group showed functional deficits in two or more domains, whereas less than 20% of the OI group did so.

Duration of unconsciousness and lowest GCS score also were significant predictors of patterns of deficits across time and total number of deficits. These results are consistent with our previous findings from this study, as well as with other research demonstrating that injury severity is a key predictor of outcome in childhood TBI (Anderson et al., 1997, 2005; Kinsella et al., 1999; Schwartz et al., 2003; Taylor et al., 2002; Yeates et al., 2001). We were unable to compare the two measures as predictors of outcomes directly, because of their high correlation. However, duration of unconsciousness was a significant predictor of outcomes in a somewhat different set of domains (i.e., neuropsychological, adaptive, academic) than was lowest GCS score (i.e., behavioral, adaptive). Thus, neither predictor appears to be consistently superior to the other, consistent with previous research on the ability of measures of TBI severity to predict neurobehavioral and functional outcomes (Massagli, Michaud, & Rivara, 1996; McDonald et al., 1994).

As hypothesized, children in the severe TBI group not only were more likely to show persistent functional deficits across domains, but also were significantly more likely to display a pattern of deterioration in behavioral outcomes. The latter findings suggest the delayed onset of significant behavior problems for some children with TBI. This result is consistent with our previous findings, as well as with other studies showing that behavior problems in children with severe TBI persist past 1 year post injury, and highlights the specific incidence of delayed behavior problems in individual children following a severe TBI (Max et al., 1997; Schwartz et al., 2003; Taylor et al., 1999, 2002; Yeates & Taylor, 2006). Anderson et al. (2005) specifically demonstrated comparable findings, such that children with severe TBI showed increased behavioral impairment by 30 months post injury.

Again as predicted, we found that improvement in neuropsychological and academic domains was more common among children with severe TBI. For instance, 11% of children with severe TBI demonstrated improvement in neuropsychological functioning over time compared to only 3% of children with moderate TBI and 5% of children with OI. This is consistent with a study by Jaffe et al. (1995) that showed improvements in academic and neuropsychological functioning during the first year post-injury, with persistent deficits continuing across 3 years.

Although not a primary focus, our analyses also showed that children's premorbid functioning helped account for functional outcomes. For instance, poorer premorbid behavioral and adaptive functioning predicted persistent neuropsychological, behavioral, and adaptive deficits. Worse premorbid behavioral functioning also predicted deterioration in behavioral and adaptive functioning. These findings are in line with previous studies on this cohort by Schwartz et al. (2003) and Taylor et al. (2002), showing that preinjury behavioral adjustment predicts the onset of behavior problems after injury. Anderson et al. (1997) reported similar findings, with preinjury adaptive functioning predicting intellectual functioning at 12 months post-injury in children with moderate and severe TBI. We also found that lower premorbid school competence was associated with persistent neuropsychological deficits and

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deterioration in adaptive and academic functioning. Additionally, low socioeconomic status was consistently associated with persistent deficits in all domains. Taken together, these findings indicate that children with poorer premorbid functioning and less advantaged family environments are at greater risk for persistent functional deficits and deterioration in many domains of functioning.

In summary, our findings build on the existing literature by demonstrating that a significant proportion of children demonstrate functional deficits following severe TBI, and those who do so are at risk for persistent deficits, even many years after recovery. The results also indicate that some children with severe TBI demonstrate recovery in academic and neuropsychological domains, but some show the delayed onset of significant behavioral problems. Children with better premorbid functioning may have a greater chance of recovery or improvement over time, while those with significant preinjury problems may be more likely to display negative long-term sequelae of TBI.

At the same time, the findings also indicate that many children with moderate to severe TBI actually show few functional deficits. Indeed, one of the central findings presented here is that the TBI groups demonstrate less functional impairment than might have been expected based on existing research, which generally uses a variable-centered approach that focuses on the statistical significance of group differences in mean scores. Variable-centered analyses may lead to an overestimation of the incidence of individual deficits following TBI, because the conclusions drawn are based on groups that show considerable overlap in the distribution of scores, even in the presence of a significant differences with effect sizes of the magnitude often found in studies of TBI (i.e., .5 to 1 standard deviation). Our findings are based on individual scores rather than group means, as well as on reasonably stringent definitions of clinical impairment; they therefore provide an important and different perspective on the nature of deficits following childhood TBI.

A limitation of this study is the use of a cutoff score to classify functional deficits. Cutoff scores have inherent limitations, but are a convenient means of differentiating typical from atypical performance. Any choice of a cutoff score is somewhat arbitrary, although we chose a cutoff often considered to represent significant impairment in clinical neuropsychological practice. A more liberal cutoff (e.g. 15$^{th}$ percentile) would have led to the identification of more functional deficits, even in the OI group. A more conservative cutoff (e.g. 5$^{th}$ percentile) would have resulted in the identification of few functional deficits, even among children with TBI. In either instance, however, similar differences would have been found between the TBI and OI groups in the relative incidence of deficits.

One concern about the use of cutoff scores is that they may not result in reliable classification, because changes in classification can occur with relatively trivial changes in performance. We performed follow-up analyses comparing the actual performances within outcome domains of the individuals who were classified according to their patterns of functional deficits. The analyses showed that the groups displayed significantly different patterns of mean scores in each outcome domain across time (i.e., neuropsychological, behavioral, adaptive and academic). Moreover, the mean scores showed significantly different trends across time, consistent with the patterns of functional deficits into which they were classified (i.e., no deficits, persistent deficits, improvement, and deterioration). Thus, the classification of individual functional deficits across time was associated with corresponding group change or stability in mean scores within domains.

Alternatively, we could have calculated a Reliable Change Index (RCI) to determine whether the difference between initial and subsequent test scores from the same examinee could be attributed to measurement error (Jacobson & Truax, 1991; Jacobsen et al., 1999; Slick,

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2006). However, a RCI can only be used with two time points, whereas our study examined outcome over three time points. Additionally, RCI applies to a single measure, whereas some of the outcomes in the current study were assessed based on multiple indices (e.g., neuropsychological functioning). Perhaps more importantly, a significant RCI can occur even when neither score being compared is normatively atypical, and therefore would not necessarily have functional implications (Slick, 2006). We were interested in whether or not each child demonstrated a functional deficit at each time point, not whether the change from baseline was significant. In clinical practice, neuropsychologists scrutinize individual test scores to determine whether or not a child evidences functional impairment. This study used similar methods to examine the functional outcomes of children with TBI.

The study was also limited because environmental variables were examined only as covariates in the prediction of functional outcomes, rather than as potential moderators, as we have done in past studies (Taylor et al., 2002; Yeates et al., 2002). We attempted to assess the effects of interactions of injury severity with environmental variables in the multinomial logistic regression analyses. However, in three out of the four cases, entry of the interaction terms led to Hessian singularities or problems of convergence. This is most likely a function of the multicollinearity between interaction terms, as well as the relatively small number of cases within some of the groups of longitudinal patterns. Future studies with larger sample sizes will be needed to investigate the moderating effects of environmental variables on functional outcomes after childhood TBI. Another limitation in our analysis is that we did not use advanced statistical techniques that derives patterns of outcomes across time empirically (e.g., latent transition analysis, latent class growth analysis), largely because our sample size would not necessarily support such techniques (Muthén & Muthén, 2000).

Another limitation shared by many studies of childhood TBI is that children's behavioral and adaptive functioning, as well as family functioning and environmental stress, were all assessed by parent report. In addition, the parent's ratings of premorbid functioning were unavoidably retrospective. Additionally, families of children with TBI who did not return for follow-up were of lower SES than those who remained in the study. Because the outcomes examined in this study are influenced by socioeconomic status, and the TBI participants who remained in the study were of higher SES than those who did not, our results may underestimate somewhat the proportion of functional deficits that occur after pediatric TBI. However, because we controlled for socioeconomic status in our analyses and found no other demographic differences between groups, group differences in functional deficits are unlikely to be strongly impacted by this bias. A final limitation is that follow-ups assessments were not completed between 1 and 4 years post injury; more frequent follow-ups would have allowed for a more precise description and categorization of longitudinal patterns of outcome.

Despite these limitations, the current results indicate that children show significant variation in their functioning after a moderate to severe TBI, with a substantial proportion actually showing relatively few functional deficits during recovery. We found that a child's individual pattern of functional deficits after a moderate to severe TBI is likely determined by a variety of factors, including severity of injury, premorbid functioning, and environmental factors such as socioeconomic status. Notably, functional deficits were not uncommon in the severe TBI group. Approximately two out of five children with severe TBI demonstrated two or more functional deficits that persisted more than 4 years post injury, despite the provision of substantial clinical and educational services to many of them. These persistent deficits highlight the need for careful evaluation and ongoing monitoring of children with severe TBI throughout their recovery, because some of them will demonstrate multiple areas of functional impairment that persist for many years after their injuries. These deficits are likely to have a significant impact on children's general quality of life and presumably will necessitate ongoing intervention (Stancin et al., 2002; Yeates & Taylor, 2006). On the other hand, the findings hold

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out hope that children with severe TBI may demonstrate surprisingly few functional deficits. A goal of future research will be to further clarify the reasons for variability in outcomes among children with TBI.

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## Table 1

Group Characteristics

| | Groups | | |
|---|---|---|---|
| | **Orthopedic Injury (*N*=44)** | **Moderate TBI (*N*=40)** | **Severe TBI (*N*=37)** |
| Age at injury (years); *M (SD)* | 9.47 (1.90) | 9.49 (1.86) | 9.77 (2.18) |
| Lowest Glasgow Coma Scale Score; *M (SD)* * | n\a | 14.08 (1.74) | 4.70 (1.91) |
| Duration of Unconsciousness (days); *M (SD)* * | n\a | 0.18 (.59) | 5.11 (5.85) |
| Duration of Hospitalization (days); *M (SD)* * | 15.09 (14.47) | 6.80 (7.28) | 13.16 (9.60) |
| Injury Severity Score; *M (SD)* * | 7.27 (2.77) | 12.33 (5.68) | 19.97 (12.09) |
| Sex (% boys) | 61% | 68% | 81% |
| Ethnicity (% Caucasian)* | 57% | 75% | 81% |
| Socioeconomic Composite Index; *M (SD)* | −0.01 (.90) | −0.23 (.88) | −0.15 (.87) |
| Family composition (% two parent families) | 57% | 70% | 68% |
| Time from injury to 4 year follow-up (years); *M (SD)* | 4.18 (0.94) | 4.25 (0.84) | 4.04 (0.94) |

*Group differences significant, $p<.05$

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**Table 2**

Patterns of Functional Deficits

| | | Groups | | |
|---|---|---|---|---|
| | | **Orthopedic Injury *n* (%)** | **Moderate TBI *n* (%)** | **Severe TBI *n* (%)** |
| *Neuropsychological Outcome* | No deficits | 33 (81%) | 30 (81%) | 24 (67%) |
| | Improvement | 2 (5%) | 1 (3%) | 4 (11%) |
| | Deterioration | 4 (10%) | 1 (3%) | 2 (6%) |
| | Persistent Deficits | 2 (5%) | 5 (14%) | 6 (17%) |
| *Behavioral Outcome* | No deficits | 35 (88%) | 28 (78%) | 21 (58%) |
| | Improvement | 2 (5%) | 1 (3%) | 2 (6%) |
| | Deterioration | 2 (5%) | 2 (7%) | 7 (19%) |
| | Persistent Deficits | 1 (3%) | 5 (14%) | 6 (17%) |
| *Adaptive Outcome* | No deficits | 27 (64%) | 24 (69%) | 15 (48%) |
| | Improvement | 3 (7%) | 2 (6%) | 2 (7%) |
| | Deterioration | 10 (24%) | 7 (20%) | 7 (23%) |
| | Persistent Deficits | 2 (5%) | 2 (6%) | 7 (23%) |
| *Academic Outcome* | No deficits | 34 (81%) | 29 (74%) | 21 (58%) |
| | Improvement | 2 (5%) | 4 (10%) | 5 (14%) |
| | Deterioration | 3 (7%) | 3 (8%) | 3 (8%) |
| | Persistent Deficits | 3 (7%) | 3 (8%) | 7 (19%) |

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## Table 3

Multinomial Logistic Regression results showing Significant Predictors of each Longitudinal Pattern: Total Group (OI and TBI)

| | Variable | B (S.E.) | OR (95% C.I.) | *P* |
|---|---|---|---|---|
| *Neuropsychological Outcome* | | | | |
| Improvement | No significant results | | | |
| Deterioration | No significant results | | | |
| Persistent Deficits | Socioeconomic Composite Index | 4.84 (1.81) | 125.93 (3.63-4374.77) | .01 |
| | Race (1=minority) | 3.84 (1.45) | .01 (2.70-795.15) | .01 |
| | School Competence | −.16 (.08) | .86 (.73-.99) | .04 |
| | Child Behavior Checklist Total | −.15 (.07) | .87 (.75-.99) | .05 |
| | Vineland Adaptive Behavior | −.17 (.08) | .84 (.71-.99) | .04 |
| | OI vs. Moderate TBI | −3.55 (1.73) | .03 (.001-.85) | .04 |
| | OI vs. Severe TBI | −3.64 (1.70) | .03 (.001-.73) | .03 |
| *Behavioral Outcome* | | | | |
| Improvement | Socioeconomic Composite Index | 3.46 (1.62) | 31.87 (1.33-762.95) | .03 |
| | Child Behavior Checklist Total | .25 (.09) | 1.28 (1.07-1.53) | .01 |
| Deterioration | Child Behavior Checklist Total | .15 (.06) | 1.17(1.04-1.32) | .01 |
| | Vineland Adaptive Behavior | .10 (.05) | 1.10 (1.01-.1.20) | .03 |
| | OI vs. Severe TBI | −3.55 (1.23) | .03 (.003-.32) | .004 |
| Persistent Deficits | Socioeconomic Composite Index | 4.59 (1.69) | 98.04 (3.57-2694.87) | .01 |
| | Child Behavior Checklist Total | .37 (.11) | 1.45 (1.16-1.80) | .001 |
| | Vineland Adaptive Behavior | .15 (.07) | 1.16 (1.02-1.33) | .03 |
| | OI vs. Severe TBI | −6.37 (2.63) | .002 (0.00-.30) | .02 |
| *Adaptive Outcome* | | | | |
| Improvement | Child Behavior Checklist Total | .18 (.08) | 1.20 (1.03-1.40) | .02 |
| | Vineland Adaptive Behavior | −.21 (.10) | .81 (.66-.98) | .03 |
| Deterioration | Race (1=minority) | 1.47 (.73) | 4.36 (1.05-18.08) | .04 |
| | Life Stressors & Resources Inventory-A | .14 (.07) | 1.15 (1.01-1.31) | .03 |
| | School Competence | −.10 (.04) | .90 (.83-.98) | .02 |
| Persistent Deficits | Child Behavior Checklist Total | .23 (.08) | 1.25 (1.07-1.46) | .01 |
| | OI vs. Severe TBI | −3.81 (1.54) | .02 (.001-.45) | .01 |
| *Academic Outcome* | | | | |
| Improvement | Life Stressors & Resources Inventory-A | −.18 (.09) | .83 (.70-.99) | .04 |
| | Vineland Adaptive Behavior | −.10 (.05) | .90 (.82-.99) | .04 |
| Deterioration | Socioeconomic Composite Index | 3.91 (1.56) | 49.89 (2.36-1056.52) | .01 |
| | Family Functioning (FAD) | −3.96 (1.99) | .02 (.00-.96) | .05 |
| | School Competence | −.45 (.16) | .64 (.47-.87) | .01 |
| Persistent Deficits | Socioeconomic Composite Index | 8.37 (3.27) | 4328.47 (7.19-2604821.99) | .01 |
| | Vineland Adaptive Behavior | −.12 (.06) | .89 (.79-.99) | .05 |
| | OI vs. Severe TBI | −3.77 (1.68) | .02 (.00-.61) | .02 |

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**Table 4**

Total Number of Functional Deficits across Domains by Group

| | | **Groups** | | |
|---|---|---|---|---|
| | | **Orthopedic Injury *n* (%)** | **Moderate TBI *n* (%)** | **Severe TBI *n* (%)** |
| *Total Deficits at 6 months post-injury* | No deficits | 31 (71%) | 24 (60%) | 17 (46%) |
| | One deficit | 8 (18%) | 9 (23%) | 6 (16%) |
| | Two deficits | 2 (5%) | 4 (10%) | 5 (14%) |
| | Three deficits | 1 (2%) | 2 (5%) | 7 (19%) |
| | Four deficits | 2 (5%) | 1 (3%) | 2 (5%) |
| *Total Deficits at 1 year post-injury* | No deficits | 33 (75%) | 22 (55%) | 16 (43%) |
| | One deficit | 4 (9%) | 10 (25%) | 7 (19%) |
| | Two deficits | 6 (14%) | 3 (8%) | 8 (22%) |
| | Three deficits | 1 (2%) | 3 (8%) | 4 (11%) |
| | Four deficits | 0 (0%) | 2 (5%) | 2 (5%) |
| *Total Deficits at 4 years post-injury* | No deficits | 26 (59%) | 22 (55%) | 14 (38%) |
| | One deficit | 12 (27%) | 10 (25%) | 8 (22%) |
| | Two deficits | 1 (2%) | 4 (10%) | 6 (16%) |
| | Three deficits | 2 (5%) | 2 (5%) | 5 (14%) |
| | Four deficits | 3 (7%) | 2 (5%) | 4 (11%) |

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## Table 5

Multinomial Logistic Regression showing Significant Predictors of Outcome: TBI Group only Index of Severity = Duration of Unconsciousness

| | Variable | B (S.E.) | OR (95% C.I.) | *p* |
|---|---|---|---|---|
| *Neuropsychological Outcome* | | | | |
| Improvement | Duration of Unconsciousness | .34 (.14) | 1.41 (1.07-1.85) | .01 |
| Deterioration | No significant results | | | |
| Persistent Deficits | Socioeconomic Composite Index | 25.38 (11.66) | 0.00 (12.47-0.00) | .03 |
| | Race (1=minority) | 34.60 (16.99) | 0.00 (3.67-0.00) | .04 |
| | Duration of Unconsciousness | 2.45 (1.07) | 11.55 (1.40-95.21) | .02 |
| *Behavioral Outcome* | | | | |
| Improvement | No significant results | | | |
| Deterioration | Socioeconomic Composite Index | 1.71 (.81) | 5.55 (1.14-27.03) | .03 |
| | Child Behavior Checklist Total | .15 (.07) | 1.15 (1.01-.1.32) | .04 |
| Persistent Deficits | Socioeconomic Composite Index | 8.30 (3.43) | 4011.186 (4.84-3325495.92) | .02 |
| | Child Behavior Checklist Total | .48 (.18) | 1.61 (1.14-2.28) | .01 |
| | Race (1=minority) | −4.94 (2.42) | 0.00 (0.00-.83) | .01 |
| *Adaptive Outcome* | | | | |
| Improvement | Child Behavior Checklist Total | .57 (.22) | 1.78 (1.15-2.74) | .01 |
| | Duration of Unconsciousness | .44 (.17) | 1.55 (1.12-2.14) | .01 |
| Deterioration | Child Behavior Checklist Total | .15 (.07) | 1.16 (1.02-1.32) | .02 |
| Persistent Deficits | Socioeconomic Composite Index | 2.88 (1.23) | 17.89 (1.61-199.14) | .02 |
| | Child Behavior Checklist Total | .25 (.10) | 1.28 (1.05-1.57) | .01 |
| | Vineland Adaptive Behavior | −.22 (.10) | .80 (.66-.97) | .02 |
| *Academic Outcome* | | | | |
| Improvement | Child Behavior Checklist Total | .18 (.07) | 1.20 (1.04-1.37) | .01 |
| | Duration of Unconsciousness | .24 (.10) | 1.27 (1.03-1.55) | .02 |
| Deterioration | School Competence | −.28 (.11) | .76 (.61-.93) | .01 |
| Persistent Deficits | Socioeconomic Composite Index | 7.57 (2.60) | 1933.116 (11.75-318073.99) | .01 |

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## Table 6

Multinomial Logistic Regression showing Significant Predictors of Outcome: TBI Group only Index of Severity = Lowest Glasgow Coma Scale Score

| | **Variable** | **B (S.E.)** | **OR (95% C.I.)** | ***p*** |
|---|---|---|---|---|
| *Neuropsychological Outcome* | | | | |
| Improvement | No significant results | | | |
| Deterioration | No significant results | | | |
| Persistent Deficits | Socioeconomic Composite Index | 3.52 (1.54) | 33.73 (1.66-684.12) | .02 |
| | Race (1=minority) | 3.46 (1.49) | 31.77 (1.70-592.79) | .02 |
| *Behavioral Outcome* | | | | |
| Improvement | No significant results | | | |
| Deterioration | Socioeconomic Composite Index | 2.49 (1.02) | 12.09 (1.65-88.66) | .01 |
| | Child Behavior Checklist Total | .26 (.11) | 1.29 (1.05-1.59) | .01 |
| | Vineland Adaptive Behavior | .13 (.06) | 1.14 (1.00-1.29) | .05 |
| | Lowest GCS | −.30 (.14) | .74 (.57-.97) | .03 |
| Persistent Deficits | Socioeconomic Composite Index | 9.36 (4.15) | 11638.42 (3.40-39879659.08) | .02 |
| | Race (1=minority) | −6.06 (2.96) | .002 (0.00-.77) | .04 |
| | Child Behavior Checklist Total | .60 (.23) | 1.82 (1.17-2.84) | .01 |
| *Adaptive Outcome* | | | | |
| Improvement | Child Behavior Checklist Total | .59 (.19) | 1.81 (1.24-2.63) | .002 |
| | Lowest GCS | −.73 (.32) | .48 (.26-.91) | .02 |
| Deterioration | Child Behavior Checklist Total | .19 (.08) | 1.21 (1.02-1.43) | .02 |
| Persistent Deficits | Socioeconomic Composite Index | 4.60 (1.83) | 99.84 (2.78-3583.95) | .01 |
| | Child Behavior Checklist Total | .65 (.23) | 1.92 (1.23-2.99) | .004 |
| | Lowest GCS | −1.17 (.43) | .31 (.14-.72) | .01 |
| *Academic Outcome* | | | | |
| Improvement | Child Behavior Checklist Total | .17 (.07) | 1.19 (1.04-1.36) | .01 |
| Deterioration | Socioeconomic Composite Index | 12.34 (6.05) | 227753.62 (1.63-31812993316) | .04 |
| Persistent Deficits | Socioeconomic Composite Index | 20.35 (9.63) | 0.00 (4.38-0.00) | .04 |