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Longitudinal neuropsychological outcome in infants and preschoolers with traumatic brain injury

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Abstract

Neuropsychological outcome was evaluated in a prospective, longitudinal follow-up study of children age 4 months to 7 years at injury with either mild-to-moderate ($N = 35$) or severe ($N = 44$) traumatic brain injury (TBI). Age-appropriate tests were administered at baseline, 6 months, 12 months, and 24 months after the injury. Performance was compared on (1) composite IQ and motor, (2) receptive and expressive language, and (3) Verbal and Perceptual–Performance IQ scores. In comparison to mild-to-moderate TBI, severe TBI in infants and preschoolers produced deficits in all areas. Interactions between task and severity of injury were obtained. Motor scores were lower than IQ scores, particularly after severe TBI. Both receptive and expressive scores were reduced following severe TBI. Expressive language scores were lower than receptive language scores for children sustaining mild-to-moderate TBI. While severe TBI lowered both Verbal and Perceptual– Performance IQ scores, Verbal IQ scores were significantly lower than Perceptual–Performance IQ scores after mild-to-moderate TBI. Mild injuries may produce subtle linguistic changes adversely impacting estimates of Verbal IQ and expressive language. Within the limited age range evaluated within this study, age at injury was unrelated to test scores: The impact of TBI was comparable in children ages 4 to 41 months *versus* 42 to 72 months at the time of injury. All neuropsychological scores improved significantly from baseline to the 6-month follow-up. However, no further change in scores was observed from 6 to 24 months after the injury. The persistent deficits and lack of catch-up over time suggest a reduction in the rate of acquisition of new skills after severe TBI. Methodological issues in longitudinal studies of young children were discussed. (*JINS*, 1997, *3*, 581–591.)

Keywords: Brain injury, Children, Infants, Neuropsychology, Outcome

INTRODUCTION

Traumatic brain injury (TBI) is a major cause of death and disability during infancy and childhood. Nearly 40% of fatalities in children from 1 to 4 years of age and 70% of fatalities in all children ages 5 to 19 years are related to injuries. Approximately 30% of all deaths related to childhood injury result from a head injury (Division of Injury Control, 1990). The Centers for Disease Control estimated the incidence of TBI at approximately 200:100,000 children per year in the United States (Division of Injury Control, 1990). Although children less than 5 years of age have the lowest rate of TBI (117:100,000; Klauber et al., 1981), the severity of injury is disproportionately high. Kraus et al. (1990) found that 24% of infants and young adults had moderate, severe, or fatal brain injuries, a rate that is higher than for other age ranges. This reflects disproportionate injury in young children since the overall incidence of severe injury requiring hospitalization is 5%. Falls, motor vehicle accidents, and assault accounted for the majority of injuries in infants and preschool-aged children. The male to female incidence ratio varies from 1.3 to 1.8 males per female injured in the age ranges of 0 to 7 (Kraus, 1995).

Within the pediatric age range, studies evaluating neurobehavioral outcome following TBI have often identified higher rates of mortality and morbidity in infants and pre-

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schoolers than in school-age children and adolescents. The Traumatic Coma Data Bank reported a mortality rate of 62% in children ages birth through 4 years and a mortality rate of 20% in children ages 5 to 10 years at 1 year following the injury (Levin et al., 1992) The less favorable outcomes in young children may be related in part to a higher incidence of inflicted injuries secondary to physical child abuse, a common cause of TBI for children less than 6 years of age (Ewing-Cobbs et al., 1995). Inflicted injuries are often associated with severe brain injury (Duhaime et al., 1992; Ewing-Cobbs et al., 1995). Most studies examining different age groups within the pediatric population have identified high mortality rates and less favorable neurobehavioral outcomes in infants and preschoolers (Jennett et al., 1979; Raimondi & Hirschauer, 1984; Luerssen et al., 1988; Michaud et al., 1992).

Evaluations of neuropsychological outcome following pediatric TBI have been focused almost exclusively on school-age children and adolescents. Follow-up studies of severe TBI in this age range have identified deficits on Performance IQ, speeded motor, visual attention, verbal memory, language, academic, and somatosensory areas (Klonoff et al., 1977; Levin & Eisenberg, 1979; Chadwick et al., 1981b; Winogron et al., 1984; Bawden et al., 1985; Ewing-Cobbs et al., 1987; Levin et al., 1988, 1994; Chapman et al., 1992; Jaffe et al., 1993; Kaufmann et al., 1993; Thompson et al., 1994; Kinsella et al., 1995; Yeates et al., 1995). Few studies have examined cognitive and motor sequelae following TBI in infants and preschool-age children. The few studies that assessed the consequences of TBI for infants and/or preschoolers identified lower IQ scores in infants and young children than in older children (Brink et al., 1970; Lange-Cosack et al., 1979).

The relationship between age at the time of TBI and subsequent cognitive development is unclear. In studies examining global outcome ratings for cognitive, social, academic, and vocational domains, some investigators have noted that age at injury was not predictive of long-term outcome following severe TBI (Costeff et al., 1990), while others have identified less favorable outcomes in children age 0 to 6 than in older children (Filley et al., 1987; Kriel et al., 1989). Several psychometric studies of outcome failed to find associations between age at injury and either severity of cognitive sequelae, rate of recovery of neuropsychological skills (Klonoff et al., 1977; Chadwick et al., 1981a, 1981b), or behavioral disturbance (Fletcher et al., 1990). In contrast, other studies have found that TBI results in more severe impairments in language, attention, visual–motor, fine motor speed, and tactile recognition in younger than in older children (Ewing-Cobbs et al., 1987; Kaufmann et al., 1993; Thompson et al., 1994).

Longitudinal studies examining neuropsychological development following TBI sustained during the preschool years have suggested that certain skills are more vulnerable than others to early injury. Early TBI has been related to slower than expected rates of development over time on Performance IQ (Anderson & Moore, 1995), expressive language (Ewing-Cobbs et al., 1989), reading (Shaffer et al., 1980), and visual closure scores (Wrightson et al., 1995). In one study, IQ scores were markedly lower and showed little increase over time in preschoolers than older children and adolescents following penetrating brain injury (Ewing-Cobbs et al., 1994).

Anderson and Moore (1995) compared change over time in Verbal and Performance IQ scores in children age 4 to 6 and 7 to 14 who sustained moderate to severe TBI. Analysis of variance did not reveal age differences in Wechsler Verbal or Full Scale IQs obtained at 4 months or 2 years following the injury. These scores were stable over time, with no significant change noted over the 2-year follow-up. Even though the Performance IQ score did not vary according to age at injury, a greater increase in the Performance IQ was noted in the older group relative to the younger group by 2 years after the injury. Although IQ scores showed relative stability during the 2-year follow-up, Anderson and Moore (1995) inferred that injuries sustained during early childhood were associated with lesser increases in cognitive ability, especially as measured by the Wechsler Performance IQ, than in older children and adolescents.

In another longitudinal study, Ewing-Cobbs et al. (1989) followed 21 children age 4 months through 5 years of age at injury over a mean follow-up interval of 8 months. Patients with severe TBI were significantly more impaired than children with mild to moderate injuries on initial assessments of intelligence, motor functioning, expressive language, and receptive language. Although there was significant recovery in intelligence, motor, and expressive language skills 8 months after the injury, children with severe injuries continued to perform below children with mild to moderate injuries on all of the measures. Comparison of the ability areas independent of injury severity indicated that motor scores were significantly more impaired than IQ scores at both time points. Expressive language was initially reduced relative to receptive language; however, performance was comparable in both areas at the final follow-up. Age-normed scores on both intelligence and motor tests were comparable across the age range. However, the youngest children, who were less than 31 months of age at injury, had greater deficits in expressive and receptive language abilities at the initial assessment compared to older children; the expressive language difficulty persisted through the follow-up.

In a longitudinal study of preschoolers with mild TBI, Wrightson et al. (1995) failed to find differences between controls and children 2.5 to 4.5 years of age sustaining mild TBI on a variety of cognitive tasks soon after the injury. However, 6 and 12 months after injury, the mild TBI group scored below controls on a visual closure task involving rapid identification of objects embedded in pictures. At age 6.5 years, low scores on the visual closure task were associated with low scores on a reading task in the mild TBI group. However, it is unclear whether these findings were a direct consequence of mild TBI. The mild TBI group may have differed from the control group in terms of developmental factors independent of TBI, such as specific developmental learning disabilities or attentional deficits, which are not manifested until later in development.

The influence of age at injury on developmental outcomes following early brain injury interacts with a variety of factors. As noted by St. James-Roberts (1979), the functional maturation of the damaged substrate, age at injury, age at assessment, testing procedures, type of brain injury, and environmental factors interact to influence outcome. More recently, researchers have questioned the hypothesis that recovery is enhanced following early brain injury. In particular, a variety of evidence suggests that generalized brain injury may be associated with more severe consequences for younger children (Levin et al., 1984; Anderson et al., 1994; Radcliffe et al., 1994). A number of findings regarding the language and memory sequelae of TBI in infants, school-age children, and adolescents are also consistent with the hypothesis that skills in a rapid stage of development at the time of TBI were more adversely affected than well-established skills (Ewing-Cobbs et al., 1987, 1989; Levin et al., 1988).

Developmental consequences of early brain injury may include the failure of more complex cognitive abilities to develop at age-appropriate rates. Assessment of the *rate* of development over time is thus critical to identify developmental lags, developmental delays, or recovery of function following a significant brain injury. As described by Fletcher et al. (1987), a developmental analysis of behavior requires assessment of the rate, sequence, onset, and degree of development of a particular ability. To date, however, there have been few longitudinal studies of children with TBI. Additional work is needed to clarify relationships between age at injury, injury characteristics and severity, type of task, and the course of recovery from TBI in young children. Available studies are limited in terms of the length of the follow-up interval, evaluation of age-related change over time, range of neuropsychological measures employed, inclusion of comparison groups, careful characterization of injury severity, and sample size.

The purpose of the present study was to evaluate acute neuropsychological deficits and long-term recovery following TBI sustained during infancy and early childhood. Four major hypotheses were evaluated: (1) severe TBI would be associated with widespread neuropsychological deficits as indicated by reduced scores on measures of intelligence, motor skills, and language functions; (2) children between the ages of birth and 41 months at injury would show a reduction in Verbal IQ and expressive language in comparison to children who were 42 through 71 months of age at injury; (3) the extent of neuropsychological impairment would vary across different areas of functioning, with expressive language and motor functions being more impaired and showing less recovery over time than composite IQ and receptive language functions (Ewing-Cobbs et al., 1989); and (4) most recovery would occur within the first 6 months after injury, with no significant change noted from 6 to 24 months on all outcome measures (Chadwick et al., 1981a; Jaffee et al., 1993).

METHODS

Research Participants

Neuropsychological outcome was evaluated prospectively in children between the ages of birth and 7 years at injury who were hospitalized at either the Hermann Children's Hospital in Houston, Texas, or John Sealy Hospital in Galveston, Texas, following either mild-to-moderate ($N = 35$) or severe TBI ($N = 44$). Demographic and neurologic information for each injury severity group is provided in Table 1. Mild-to-moderate TBI produced impaired consciousness, defined as an inability to follow a one stage command, for less than 1 day, as indicated by the motor scale of the Glasgow Coma Scale score (Teasdale & Jennett, 1974). There was no documented loss of consciousness or brief loss of consciousness in 77% of the mild-to-moderate group. Severe TBI was defined by impaired consciousness persisting for at least 1 day. Since the Glasgow Coma Scale score was developed for adults, the motor scale was modified to accommodate the behavioral capabilities of children from birth through 35 months of age. Spontaneous movement in infants age 0 to 6 months and goal-directed movements in children 7 to 35 months were considered comparable to following commands in older children. The lowest postresuscitation GCS scores ranged from 3 to 8 in 3 children placed in the mild-to-moderate injury group since their inability to follow commands persisted for less than 24 hr (range = 0.3–0.75 days). As indicated in Table 1, impaired consciousness persisted for an average of 0.1 days in the mild-to-moderate TBI group and 8.4 days in the severe TBI group, with a range from 1 to 35 days. Criteria for exclusion from the study were (1) preinjury neurological or developmental disorder, (2) non-English speaking, (3) suspected child abuse, (4) penetrating brain injury, and (5) prior or subsequent TBI. Since TBI was expected to produce significant sequelae in the youngest children due to rapid development of cognitive and motor skills, age at injury was divided into two groups. The sample was divided using a median split procedure, which yielded younger (0–41 months) and older (42–71 months) groups.

The injury severity groups were comparable in terms of age at injury, ethnicity, socioeconomic status as indicated by the Hollingshead Two Factor Index, and sex. The sample was from predominantly middle-to-lower socioeconomic backgrounds, and included major ethnic groups. The external cause of injury varied with injury severity: mild-to-moderate injury was produced most frequently by falls, while motor vehicle–pedestrian injuries occurred most often in the severe TBI group. Consistent with epidemiological studies of TBI in young children, the male to female ratio was 1.4:1 (Kraus, 1995).

Procedure

Written informed consent to participate in the study was obtained during the initial hospitalization. Assessment proce-

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Table 1. Demographic and neurologic information according to severity of traumatic brain injury

Variable	Severity of injury: Mild–moderate ($N = 35$)	Severity of injury: Severe ($N = 44$)
Age at injury (months)		
M	40.1	44.8
SD	21.9	21.5
Sex (*n*)		
F	10	22
M	25	22
Socioeconomic status (*n*)		
Low	7	12
Middle	26	32
High	2	0
Ethnicity (*n*)		
African American	8	13
White	22	25
Hispanic	5	6
Glasgow Coma Scale (*n*)$^+$		
3–8	3	36
9–12	8	8
13–15	24	0
Glasgow Coma Scale$^+$		
M	13.1	6.0
SD	2.4	2.4
Days of impaired consciousness (*n*)$^+$		
0–.09	27	0
.1–0.9	8	0
1.0–6.9	0	24
7.0–35.0	0	20
Duration of impaired consciousness (days)$^+$		
M	0.1	8.4
SD	0.2	8.2
External cause of injury (*n*)		
MVA	8	12
MVA–pedestrian	6	26
Fall	15	4
Bike	2	0
Sports–Recreational	2	1
Other	2	1
CT scan findings		
Normal	7	3
Extraaxial hematoma		
Epidural	2	2
Subdural	3	8
Subarachnoid	2	10
Hemorrhagic contusion	3	17
Diffuse	0	6
Skull fracture	21	29

Note. $^+p < .0001$. MVA = motor vehicle accident.

dures and significance of the project were described to both parents and children. Verbal assent to participate was obtained from children 3 to 7 years of age.

Neuropsychological evaluation was completed at baseline following resolution of posttraumatic amnesia. Children were judged to have emerged from posttraumatic amnesia based on Children's Orientation and Amnesia Test (Ewing-Cobbs et al., 1990) scores for 3- to 7-year-olds and upon return to play activities for children age 2 years or less. The evaluations were repeated at 6, 12, and 24 months after the injury. Since no standardized assessment measures extend from infancy through middle childhood, composite scores were created based on age-appropriate assessment instruments. Standardized measures of intelligence, motor functions, and receptive and expressive language were selected. Intellectual ability was assessed using the Bayley Scales of Infant Development Mental Scale (Bayley, 1969), Stanford-Binet Intelligence Scale, Form L-M (Terman & Merrill, 1972), or the McCarthy Scales of Children's Abilities (McCarthy, 1972). Motor scores were obtained from the Bayley Scales Physical Development Index or the McCarthy Scales Motor Scale. Receptive and expressive language were assessed using the Sequenced Inventory of Communication Development–Revised (Hedrick et al., 1974). In children older than 48 months at the time of assessment, expressive language was estimated using the McCarthy Verbal Scale, and receptive language was evaluated using the Peabody Picture Vocabulary Test–Revised (Dunn & Dunn, 1981). Verbal and Perceptual–Performance IQ scores were based on children's performances on the McCarthy Scales.

To increase comparability across neuropsychological measures, scores from the McCarthy and Stanford-Binet were restandardized to yield a mean of 100 and a standard deviation of 15. The Sequenced Inventory of Communication Development–Revised scores are expressed as receptive and expressive communication ages. These scores were converted into ratio IQ equivalents, yielding a mean of 100. The standard deviation may not be directly comparable to the other measures. The IQ, motor, and language scores were combined to yield summary variables for statistical analysis. The composite intelligence variable was composed of standard scores from the Bayley, Stanford-Binet, or McCarthy tests. The composite motor score was based on the standard scores derived from either the Bayley or McCarthy Motor Scales. The receptive language composite score was based on performance on the Sequenced Inventory of Communication Development–Revised receptive scale or the Peabody Picture Vocabulary Test–Revised in the older children. Expressive language was estimated using the Sequenced Inventory of Communication Development Expressive Scale or the McCarthy Verbal Scale for older children. The composite groupings were derived based on face validity. Similar procedures for creating test composites have been used successfully in previous studies of TBI in young children (Ewing-Cobbs et al., 1989). To estimate the influence of the component tests on the composite IQ, motor, and language variables, two procedures were performed. First, the means of each component (e.g., Bayley Index, Binet IQ, McCarthy Index) of a composite score were examined collapsing over time of testing. Second, the correlation for the same test and for different tests administered at adjacent time points was calculated.

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Design

The design was mixed with age at injury (4–41, 42–71 months) and severity of injury (*mild–moderate*, *severe*) serving as between-subject factors and time of testing (baseline, 6, 12, 24 months) and task as the within-subjects factors. Using a multivariate approach to repeated measures analysis of variance (ANOVA), 2 (age) × 2 (injury severity) × 4 (time) × 2 (task) ANOVAs were completed. Age at injury and the duration of impaired consciousness were examined as both continuous and dichotomous variables. As the results of analysis were similar using either approach, age at injury, and injury severity were used as dichotomous variables. Performance was compared across three task domains to identify patterns of neuropsychological performance. Task comparisons included (1) composite IQ *versus* motor, (2) Verbal IQ *versus* Perceptual–Performance IQ, and (3) receptive *versus* expressive language scores. Similar comparisons have been made in other studies (Ewing-Cobbs et al., 1989). The fact that each pairing of measures was derived from a common test battery provided additional justification for these specific comparisons.

RESULTS

Comparison of Performance in Neuropsychological Domains

The (1) composite IQ and motor, (2) Verbal and Perceptual–Performance IQ, and (3) receptive and expressive language scores were compared to evaluate areas of relative deficit following TBI. Table 2 contains mean and standard deviation values for each dependent variable by severity group at each assessment. Table 3 contains the F and p values for main effects and interaction effects for the omnibus Severity × Age × Task × Time repeated measures ANOVAs.

Composite IQ and motor scores

For the composite IQ and motor scores, significant main effects for injury severity, task, and time were obtained. Children with severe TBI scored significantly lower than children with mild-to-moderate injuries throughout the 2-year follow-up. Motor scores were consistently lower than IQ scores at each time interval. Age at injury was not related to either IQ or motor scores. However, the Time × Severity × Task interaction was significant, indicating greater improvement over time following severe injury, particularly for motor scores. This relationship is depicted in Figure 1, which shows the steeper slope of the recovery curve for motor as compared to IQ scores in the severe TBI group from baseline to 6 months after injury.

Significant two-way interactions were obtained for the Time × Task, Time × Age, and Task × Severity effects. To examine the interactions involving time, age and task effects were explored at each of the four time points. Age × Task interactions were not obtained at any time point. However, the main effect of age was present only at the baseline evaluation [$F(1,66) = 4.99$, $p < .03$]. The mean performance of older children was lower than younger children on both IQ and motor scores. Significant task effects were obtained at the baseline [$F(1,66) = 21.3$, $p < .0001$], and 1-year [$F(1,71) = 5.81$, $p < .02$] follow-up intervals. Motor scores were lower than composite IQ scores. The Task × Severity interaction was significant only at the 2-year interval [$F(1,72) = 14.74$, $p < .0003$]. Motor scores were lower than IQ scores following severe TBI.

Table 2. Mean IQ, motor, and language scores by severity of injury and time of testing

Test domain	Time of testing: Baseline	6-month	12-month	24-month
Composite IQ				
Mild–moderate				
M	98.7	101.6	102.5	99.2
SD	16.8	15.8	13.1	13.1
Severe				
M	81.0	88.4	88.1	89.4
SD	20.0	18.9	20.4	20.7
Motor				
Mild–moderate				
M	92.0	102.1	99.8	102.9
SD	19.8	18.2	17.8	19.1
Severe				
M	68.7	83.9	81.6	80.9
SD	17.5	19.4	18.3	22.3
Verbal IQ				
Mild–moderate				
M	92.8	99.8	98.9	97.8
SD	15.5	14.3	13.4	12.7
Severe				
M	81.6	92.6	91.3	94.6
SD	15.8	17.2	17.0	19.2
Perceptual–Performance IQ				
Mild–moderate				
M	99.1	105.5	104.9	103.5
SD	13.6	13.0	14.9	16.0
Severe				
M	81.6	93.7	93.7	93.9
SD	16.2	14.3	16.8	18.7
Receptive language				
Mild–moderate				
M	92.8	96.8	96.2	93.3
SD	18.2	14.6	15.7	14.6
Severe				
M	80.8	82.0	84.8	80.8
SD	16.0	15.7	18.2	17.5
Expressive language				
Mild–moderate				
M	82.2	92.6	89.8	95.4
SD	21.1	21.1	19.9	18.2
Severe				
M	79.1	85.8	85.4	86.8
SD	16.6	19.5	19.4	23.6

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Table 3. Summary of analysis of repeated measures ANOVAs comparing performance in neuropsychological domains

	Neuropsychological domain								
	VIQ and P–PIQ			IQ and motor			Receptive and expressive language		
Effect	*F*	(*df*)	*p*	*F*	(*df*)	*p*	*F*	(*df*)	*p*
Main effects									
Severity	8.14	(1,31)	.0376	23.41	(1,74)	.0001	7.56	(1,75)	.0075
Age	0.59	(1,31)	.4775	00.53	(1,74)	.4669	0.46	(1,75)	.5014
Task	2.25	(1,209)	.1354	12.54	(1,452)	.0004	0.80	(1,477)	.3730
Time	2.29	(3,209)	.0791	14.01	(3,452)	.0001	8.83	(3,477)	.0001
Interaction effects									
Severity × Age^{+}				0.00	(1,74)	.9579	0.85	(1,75)	.3598
Time × Task	0.40	(3,209)	.7535	5.62	(3,452)	.0009	5.39	(3,477)	.0012
Task × Age	0.00	(1,209)	.9720	0.22	(1,452)	.6368	2.66	(1,477)	.1033
Severity × Task	5.18	(1,209)	.0238	5.30	(1,452)	.0218	5.29	(1,477)	.0219
Time × Task × Age	0.40	(3,209)	.7558	1.09	(3,452)	.3512	2.92	(3,477)	.0337
Time × Severity × Task	0.69	(3,209)	.5600	2.95	(3,452)	.0323	0.21	(3,477)	.8885

Note: $^{+}$Due to the younger children in this analysis, the Severity × Age interaction was not computed for the VIQ and P-PIQ variables.

Verbal IQ and Perceptual–Performance IQ scores

The sample size was smaller ($N = 34$) for the comparison of the Verbal and Perceptual–Performance IQ scores than for the other dependent variables, since younger children received Bayley and Stanford-Binet tests, which yield a single composite IQ score and could not be included in the analysis. As indicated in Table 3, the main effect for injury severity was significant: Scores were lower following severe injury. The Severity × Task interaction effect was significant. Children with mild-to-moderate TBI had lower Verbal IQ than Perceptual–Performance IQ scores [$F(1,75) = 7.48$, $p < .008$]. In contrast, children with severe TBI performed comparably on both the Verbal and Perceptual–Performance IQ scores. As seen in Figure 2, the Verbal IQ scores were lower than Perceptual–Performance IQ scores in both groups.

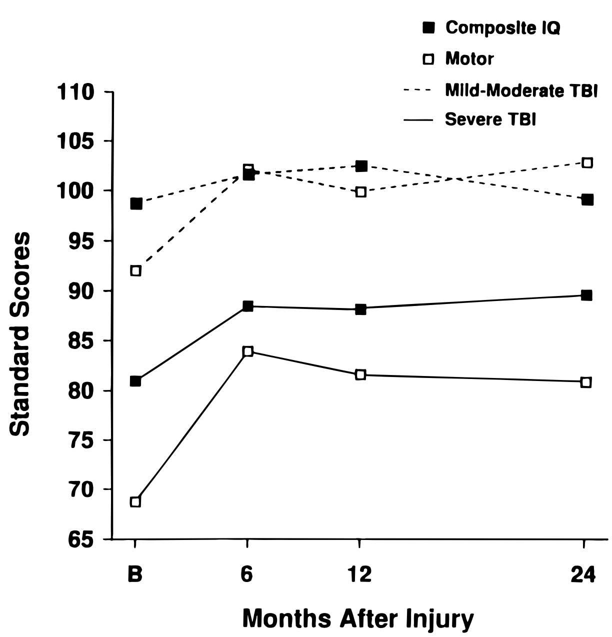

Fig. 1. Both IQ and motor scores were reduced by severe TBI throughout the 24-month follow-up. Motor scores were significantly lower than composite IQ scores.

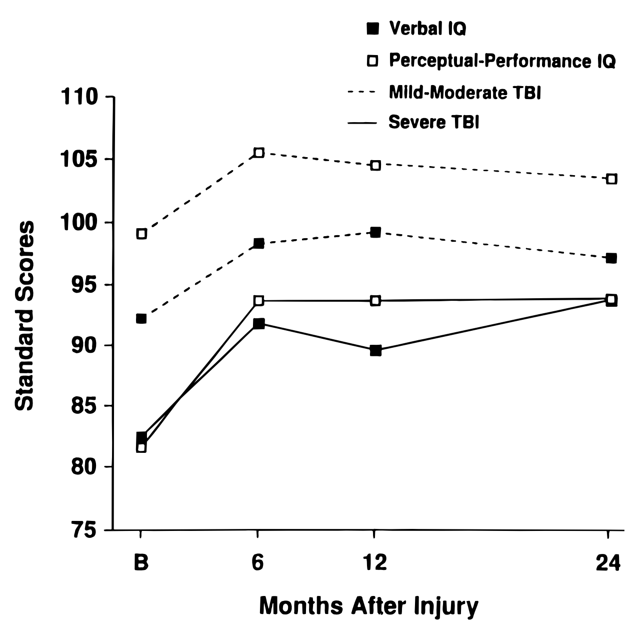

Fig. 2. Severe TBI reduced both Verbal and Perceptual–Performance IQ scores. Verbal IQ scores were significantly lower than Perceptual–Performance IQ scores following mild-to-moderate TBI.

The main effect for time was not significant. This may be due to more McCarthy scores being obtained at follow-up intervals after the initial recovery has occurred. The Severity × Age interaction was not computed because there were few children in the younger group.

Receptive and expressive language

Analysis of receptive and expressive language composite scores yielded significant main effects for injury severity and time of testing (see Table 3). In comparison to mild-to-moderate TBI, severe TBI was associated with a significant reduction on both receptive and expressive language composite scores. A significant Time × Task × Age interaction suggested differential change in composite language scores according to age at injury and time of testing. To examine this interaction, task and age were evaluated at each time interval. Neither main effects for age nor Age × Task interaction effects were obtained at any evaluation. However the task main effect was significant at the baseline [$F(69) = 6.25$, $p < .01$] and 2-year [$F(1,75) = 4.39$, $p < .04$] intervals. Expressive scores were lower at baseline while receptive scores were lower at the 2-year follow-up.

The Task × Severity interaction was significant. Children with mild-to-moderate TBI scored lower on expressive than receptive scores [$F(1,477) = 5.29$, $p < .02$], while children with severe TBI had comparable expressive and receptive scores.

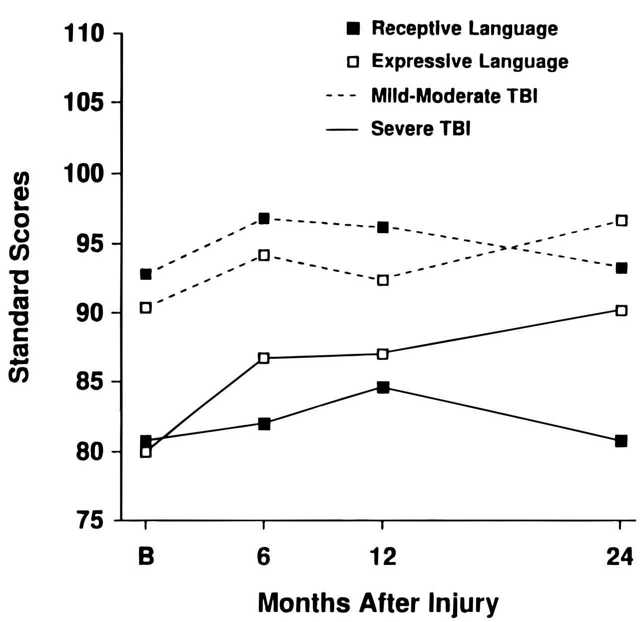

Fig. 3. Both receptive and expressive language functions were significantly lower in children with severe TBI than in children sustaining mild-to-moderate TBI. The expressive language score was significantly lower than the receptive language score following mild-to-moderate TBI.

Time of Testing

Scores increased significantly over the follow-up period in IQ, motor, and language areas. To evaluate the extent of change in composite scores over the follow-up period, planned comparisons were performed. Performance at baseline was contrasted with the average of scores obtained at 6, 12, and 24 months, to identify initial improvement consistent with recovery of function. The baseline composite IQ and motor [$F(1,477) = 33.77$, $p < .0001$], Verbal and Perceptual–Performance IQ scores [$F(1,226) = 34.87$, $p < .0001$], and language composite scores [$F(1,489) = 20.56$, $p < .0001$], differed significantly from the average follow-up scores. To assess further change over the follow-up period, scores were compared at 6, 12, and 24 months. However, no significant change in scores from 6 to 24 months was obtained for the IQ and motor [$F(2,477) = 0.01$, $p > .10$], Verbal and Perceptual–Performance IQ [$F(2,226) = 0.04$, $p > .10$], or receptive and expressive language [$F(2,489) = 0.90$, $p > .10$] composite scores.

Methodological Issues

None of the measures used in this longitudinal study encompassed the entire age range, necessitating the use of composite scores for IQ, motor, and language variables. Therefore, significant task effects could reflect either specific findings related to specific tests or to broader constructs underlying the individual tests employed. To examine the continuity over time within the composite scores, the mean values of each score within the composite score were compared. Component scores differed significantly on the composite IQ score [$F(2,76) = 3.14$, $p < .05$]. The mean Bayley score (98.7) was higher than the mean Stanford-Binet (92.8) or McCarthy (91.7) scores. The component scores for other composite scores did not differ from each other.

An alternative method for examining the stability of the composite scores is to evaluate the correlation of scores between adjacent time point using either the same or different tests. As seen in Table 4, the Pearson correlation coefficients ranged from .707 to .823 for the same test administered on consecutive occasions, indicating strong test–retest values. The coefficients were much more variable when different tests

Table 4. Correlation between the same or different tests administered at adjacent time points

	Adjacent test	
Composite score	Same	Different
IQ	.823	.805
Motor	.707	.631
Receptive	.773	.688
Expressive	.776	.341

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were administered. Moderate to strong coefficients were obtained for different IQ, motor, and receptive language measures given at adjacent time points. The components of the expressive composite score were weakly related to each other, suggesting that the construct of expressive language was more heterogeneous than other constructs.

DISCUSSION

In comparison to young children sustaining mild-to-moderate TBI, severe TBI in infants and preschoolers was associated with deficits on IQ, motor, and language measures. Analyses failed to reveal main effects for age in the omnibus tests of the IQ, motor, and language scores. Tests of the Age at Injury × Severity of Injury interaction effects were also nonsignificant, suggesting that the influence of severe TBI was comparable in the younger and older groups. Although significant improvement in scores was noted from baseline to the 6-month follow-up, no significant change in scores was identified from 6 to 24 months after the injury. These results parallel the global and persistent decrement in neuropsychological functioning described following penetrating brain injury in preschoolers (Ewing-Cobbs et al., 1994). Motor scores were the most adversely affected by severe TBI. At the 2-year follow-up, the mean motor scores remained 22 points lower in the severe injury group than in the mild–moderate injury group. Standard score differentials between severity groups varied from 9 to 12 points for other areas tested. The lack of an uninjured control group limits characterization of the consequences of TBI, and limits the detection of group differences, especially in children with mild and moderate TBI.

Comparison of performance in different neuropsychological domains indicated specific area of weakness following severe TBI. Severity × Task interactions were obtained in all three domains evaluated. Motor scores were lower than IQ scores, particularly in the children with severe injuries. Severe TBI produced comparable reduction in both Verbal and Perceptual–Performance IQ scores. In contrast, Verbal IQ scores were significantly lower than Perceptual–Performance IQ scores after mild-to-moderate TBI. Both receptive and expressive language composite scores were adversely affected by severe TBI. Expressive language scores were lower than receptive scores for children sustaining mild-to-moderate TBI.

The finding that Verbal IQ and expressive language composite scores were lower than Perceptual-Performance IQ and receptive language scores in the mild-to-moderate injury group suggests vulnerability of language to the effects of early brain injury. Mild-to-moderate TBI may produce subtle linguistic changes adversely impacting measures of Verbal IQ and language. Without a noninjured comparison group, this question cannot be directly addressed by the present data. However, the present findings are consistent with those of Chapman (1995) and Wrightson et al. (1995) in suggesting vulnerability of children sustaining TBI during the preschool years to later linguistic deficits. Clearly, the identification of linguistic sequelae in young children following mild, moderate, and severe TBI needs additional investigation. Analysis of performance on structured psychometric tests, language samples, and discourse tasks in children injured at different developmental stages is needed.

All studies reporting lower Performance IQ than Verbal IQ scores following pediatric TBI have used the Wechsler scales. As noted by Donders (1993), factor analysis of Wechsler IQ scores following head injury in children disclosed four different patterns of scores; only one of the four patterns contained a specific Performance IQ deficit relative to the Verbal IQ. In the present study, the Verbal and Perceptual–Performance IQ scores were obtained from the McCarthy Scales of Children's Abilities. The content of the McCarthy Perceptual–Performance scale differs from the Wechsler Performance Scale in that it contains subtests evaluating the development of early concepts of size, shape, color, and seriation for which there is no parallel on the Wechsler Scales. Although the McCarthy has two subtests involving visual–motor skills (Draw-A-Design and Draw-A-Person), these subtests do not have a speeded motor component. Therefore, the different response requirements of the McCarthy versus Wechsler Scales likely influenced the recovery curves obtained. The McCarthy Verbal Scale contains subtests assessing fluency, repetition, and verbal memory abilities in addition to more traditional vocabulary and reasoning abilities. The verbal fluency and memory items may be particularly sensitive to both mild-to-moderate and severe TBI.

The use of composite scores to assess long-term outcome is problematic. Of the four composite scores employed, component scores were significantly different on the IQ variable. The test–retest correlation coefficients suggested good to adequate consistently across time intervals for the IQ, motor, and receptive language composite scores. Both the same test as well as different component tests administered at adjacent time intervals showed adequate reliability. However, the components of the expressive composite variable were heterogeneous. Stronger correlations may have been obtained if specific expressive language measures had been used for the children older than 4 years of age. Alternately, using only the McCarthy subtests that assess fluency, repetition, and naming may have provided a better estimate of expressive language than the McCarthy Verbal IQ score. To estimate the effect of changing tests, administering the overlapping tests (e.g., Bayley and Binet) at a given age would also clarify differences in scores that are attributable to task differences *versus* developmental change in performance. Advances in IQ, motor, and language assessment during the past decade will enhance the characterization of neuropsychological functions following TBI in young children.

Given the reduced performance in all areas following severe TBI, it appears that severe brain injury produced widespread and persistent reduction in the neuropsychological areas evaluated. The scores of the severe TBI group did not catch up to scores of the mild-to-moderate group. The failure of the severe injury group to catch up may reflect a reduction in the rate of development of neuropsychological abilities. Although the severely injured children continue to develop, they may acquire new skills more slowly than either mildly injured children or children with a comparable level of intellectual functioning prior to TBI. Thus, over the 2-year follow-up interval, the developmental characteristics of neuropsychological change support a model showing initial deficit, variable recovery, and a stable persistent deficit over time consistent with a deficit model. There is no evidence from this or other longitudinal data of severe TBI in either young children, school aged children, or adolescents that would suggest continued gains over time. Analysis of longitudinal data using growth curve analysis may clarify issues regarding the rate and sequence of development after early brain injury.

Determination of the quality of neuropsychological outcome following TBI in infants and preschoolers is complicated by the difficulty assessing the severity of TBI in this age range. Particularly for infants, there is no universally accepted means of assessing injury severity. As noted by Ewing-Cobbs et al. (1995), the most common means of assessing injury severity in infants involves different modifications of the Glasgow Coma Scale score (Teasdale & Jennett, 1974) to accommodate the behavioral capabilities of infants. However, severe TBI during infancy may or may *not* be associated with significant alteration in consciousness. Although the duration and depth of impaired consciousness have shown strong relationships with other measures of injury severity and outcome in older populations, the adequacy of the Glasgow Coma Scale for young children has not been established (Lieh-lai et al., 1992). For example, one of the most severely disabled infants in the present sample had a lowest modified Glasgow Coma Scale score of 14 (indicating a mild TBI) despite the presence of hemiparesis, computed tomographic scan abnormalities indicating involvement of both hemispheres, and neuropsychological scores uniformly in the deficient range. In a recent study of different methods of assessing injury severity, the duration of impaired consciousness accounted for significantly more variability in a broad range of neuropsychological domains at 5 years after injury in children and adolescents than either the lowest Glasgow Coma Scale score or a composite measure of injury severity based on the Glasgow Coma Scale score, duration of impaired consciousness, and the presence of positive findings on computed tomographic scans (Ewing-Cobbs et al., 1996). While the duration of impaired consciousness may be the best measure of injury severity across the whole pediatric age range, different indices need to be developed for application to infants. CT or MRI findings may be most accurate in characterizing the severity of injury in infants.

Longitudinal follow-up of infants and preschoolers is complicated by several factors. First, there are no measures of IQ, language, or motor skills that encompass the age range from 0 to 7. Therefore, differences in the specific items administered and in standardization samples may obscure age-related changes. Moreover, since children acquire injuries at different ages, there is more variability in outcome data than is the case for populations such as premature infants or children with infantile hemiplegia. The latter populations sustain brain insult at a specific stage of development and can therefore be followed more systematically with all children in a given sample potentially eligible for the same test battery at a given point in follow-up. If children with acquired injuries are matched for age at testing, the injury test interval will differ significantly across groups. Time since injury is clearly a crucial variable following TBI, since change is most evident during the first 6 months after injury. In studies of children with perinatal injuries, the time span between injury and testing correlated significantly with IQ scores declining over time (Banich et al., 1990). While this relationship has not been shown in children with acquired injuries sustained after the perinatal period, very long-term follow-ups will be required to address issues related to the ultimate impact of early brain injury on development. Long-term follow-up should ideally encompass 10 to 20 years, so that the impact of early brain injury on later developing abilities, such as executive functions, can be evaluated (Eslinger & Damasio, 1985).

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