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Predicting recovery from head injury in young children: A prospective analysis

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Abstract

It has been argued that young children's brains are "plastic," and may sustain substantial brain insult with little loss of function. Recent research suggests that this notion may not apply for generalized cerebral pathology. The present study aimed to evaluate this proposition using a sample of 73 young children, divided into 3 groups: *severe head injury* (HI; $N = 17$); *mild–moderate HI* ($N = 32$); and noninjured controls ($N = 24$). Preinjury screening established equivalence across groups for age, sex, preinjury ability, behavioral adjustment, socioeconomic status, and family functioning. Children were evaluated as soon as possible postinjury, and again 12 months postinjury, in three domains: intellectual ability, language, and memory. Results indicated that severe HI was associated with substantial, persisting difficulties in all areas. In contrast, children with mild–moderate HI experienced fewer difficulties, and often performed similarly to controls, both acutely and 12 months postinjury. There was no evidence of differential recovery of function associated with injury severity, with performance increments consistent across groups and probably due to either age-appropriate developmental gains, or test–related practice effects. Poorer outcome at 12 months postinjury was predicted by injury severity primarily, with earlier age at injury, and premorbid ability associated with outcome in specific domains. (*JINS*, 1997, *3*, 568–580.)

Keywords: Child head injury, Recovery, Outcome

INTRODUCTION

Acquired brain injury in children is one of the most frequent causes of interruption to the normal course of development. It is estimated that as many as 250 per 100,000 children will experience a head injury (HI) in any 1 year (Kraus, 1995). While much is now known about outcome following adult HI, the nature of deficits, process of recovery, and prognostic indices remain unclear for young children. In the past it has been argued that young children's brains are "plastic," and may sustain substantial brain insult with little or no observable loss of function (Lenneberg, 1967; Smith, 1983). Recent research, investigating childhood HI, as well as other generalized cerebral trauma, suggests that the notion of plasticity may not apply where cerebral pathology is widespread (Ewing-Cobbs et al., 1987, 1994; Anderson et al., 1994; Anderson & Moore, 1995; Dennis et al., 1995). These studies describe persisting neurobehavioral deficits, providing evidence that the young child's brain may be particularly vulnerable to early trauma. Further, some researchers have argued that these deficits are not static. Declines in abilities have been reported in some groups (Anderson et al., 1995b; Anderson & Moore, 1995; Dennis et al., 1996), while others argue that children may "grow into" their deficits, with new impairments emerging as expected developmental gains are not achieved (Goldman-Rakic et al., 1983; Anderson, 1988; Banich et al., 1990; Dennis et al., 1995).

Neuropsychological studies investigating sequelae of HI in school-aged children document deficits in memory and learning (Levin et al., 1988; Yeates et al., 1995), attention (Murray et al., 1992; Kaufman et al., 1993; Dennis et al., 1995; Anderson & Pentland, in press), psychomotor skills (Bawden et al., 1985), language (Ewing-Cobbs et al., 1989; Jordan & Murdoch, 1994), and executive functions (Dennis et al., 1996; Todd et al., 1996).

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Only a handful of studies have addressed the impact of HI in very young children. Early work, employing cross-sectional designs and summary outcome measures, detected no relationship between age at injury and neurobehavioral outcome (Klonoff et al., 1977; Chadwick et al., 1981; Dennis, 1985; Tompkins et al., 1990). More recent, longitudinal research has reported that, while children sustaining early injuries may present with similar patterns of impairment, they have poorer outcomes than do children sustaining their injuries later in childhood (Lange-Cosack et al., 1979; Ewing-Cobbs et al., 1989; Kriel et al., 1989; Anderson & Moore, 1995; Wrightson et al., 1995). Further, Thompson and colleagues (Thompson et al., 1994) report that younger children with severe injuries showed slower development of motor and visuospatial skills than older children or younger children with mild head injuries.

Various factors may account for the vulnerability of the young child to significant and persistent neurobehavioral deficits following generalized cerebral insult. First, the young child's brain is incompletely developed. In the event of a blow to the head, the bone is able to absorb more of the forces of the impact, resulting in the expected focal damage, but also greater diffuse injury than may be expected with similar insult in the mature brain (Bruce, 1995). Such diffuse damage may interrupt ongoing cerebral development, including neuronal myelination and frontal lobe maturation, which are thought to be particularly rapid during the first 5 years of life (Hudspeth & Pribram, 1990; Thatcher, 1991). From a cognitive perspective, young children possess fewer consolidated abilities. The younger the age at injury, the fewer mature cognitive skills established by the child. Future acquisition of these skills may be compromised, depending on the nature and severity of the cerebral damage (Dennis, 1989). If this is the case, then young children may appear to have few observable deficits in the early stages of recovery. However, impairments may emerge with time, as the impact of poor skill acquisition results in increasing discrepancies between the HI child and age peers. Further, as the child moves through childhood and is required to function more independently, information processing skills and executive functions, subsumed by areas of the brain that are immature during early childhood, and thus susceptible to the impact of brain insult, may fail to emerge (Kennard, 1940; Finger & Stein, 1982; Dennis, 1989; Dennis et al., 1995).

While age at insult may be predictive of poorer outcome following childhood HI, no single factor can account for the wide variability in recovery patterns and outcomes observed in pediatric populations (Fletcher et al., 1995). Rather, it is likely that several mechanisms may be acting, both independently and interactively, to determine prognosis. For example, it is reasonably well established that injury severity, as measured by Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974) or posttraumatic amnesia (PTA), represents a reliable predictor of neuropsychological outcome, with more severe HI related to greater declines in neurobehavioral functioning (Winogron et al., 1984; Fletcher et al., 1990; Michaud et al., 1992; Jaffe et al., 1993; Dennis et al., 1995).

Preinjury abilities and environmental factors, such as socioeconomic status (SES) and family functioning, may also contribute to risk of injury and long-term outcome (Rivara et al., 1993, 1994; Taylor et al., 1995). Several studies have indicated that low levels of maternal education and lower SES may be associated with increased risk of accident (Bijur et al., 1988; Larson & Pless, 1988; Coster et al., 1994). Some studies go so far as to suggest that postinjury psychosocial problems reflect premorbid family dysfunction, rather than injury-related factors (Casey et al., 1986). Two recent studies query such statements, presenting findings that suggest that premorbid psychosocial disturbances are no more common in HI children than in the general population (Donders, 1992; Prior et al., 1994). Donders (1992) compared injuries defined as high risk (e.g., falls, pedestrian accidents, where children put themselves in danger) and low risk (e.g., where the child is a passenger in a motor vehicle accident), and found no differences in premorbid behavioral patterns across groups, refuting the view that HI children are an unrepresentative group, more likely to have preexisting behavioral problems that place them at increased risk of injury.

Similarly, psychosocial variables have been implicated as predictors of long-term prognosis, regardless of age at injury or injury severity (Perrot et al., 1991; Coster et al., 1994; Taylor et al., 1995). Brown and associates (Brown et al., 1981) have documented increased risk of psychiatric disorder for children in families experiencing psychosocial adversity, including marital problems or parental mental disorder. Best outcomes have been associated with good social support and family cohesion. Rivara and colleagues (Rivara et al., 1993) have shown that, in school-aged children, high levels of family cohesion and low levels of parental control are predictive of good child adaptive functioning, social competence, and global functioning at 1 year postinjury. For the young child, who may be interacting primarily within the home environment, these psychosocial factors may be particularly important. The child is dependent on the family for providing an appropriate environment, for allowing access to rehabilitation resources, and supporting therapies at home.

While individual predictors of outcome can be evaluated largely in isolation, it is most likely that these factors will interact to determine long-term outcome. Some researchers have begun to address this possibility, suggesting a "double hazard" hypothesis where psychosocial and injury variables interact to determine prognosis (Breslau, 1990; Taylor et al., 1992). Thus, the difference between children sustaining severe injuries and controls would be least when injured children were from socially advantaged backgrounds, and greater for those from socially disadvantaged environments. Some evidence to support such a position comes from research investigating low-birth-weight children (Breslau, 1990), or those contracting meningitis in infancy and early childhood (Taylor et al., 1992).

The present study aimed to investigate prognosis following HI early in childhood, with particular emphasis on predictors of outcome. The impact of premorbid characteristics, psychosocial factors, and injury variables were evaluated in relation to neuropsychological abilities and patterns of recovery in the initial 12 months following HI. Specifically, and in keeping with vulnerability models, it was predicted that young children sustaining HI would experience deficits in all areas of functioning, with better recovery for milder injuries. Further, injury severity, age at injury, and premorbid abilities would be associated with outcome 12 months postinjury.

METHODS

Research Participants

Seventy-three children participated in the study. Forty-nine children diagnosed as sustaining HI were recruited from consecutive admissions to the neurosurgical ward of the Royal Children's Hospital, Melbourne. Inclusion criteria were: (1) age at injury 2 to 7 years; (2) documented evidence of HI; and (3) period of altered consciousness. The remaining 24 children made up the noninjured comparison group; these were identified *via* schools and child care centers, and selected to match the HI sample as closely as possible for age, sex, and SES. Exclusion criteria for all participants were history of previous HI, and evidence of preexisting physical, neurological, psychiatric, or developmental disorder. Within the HI sample, children were classified into groups according to severity of injury, as follows: (1) *mild–moderate HI* ($N = 32$): GCS on admission 9 to 15; (2) severe HI ($N = 17$): GCS on admission 3 to 8; mass lesion or other evidence of specific injury. Injury characteristics of the head-injured children are reported in Table 1.

In total, 63 children sustaining HI were invited to enroll in the study. Five families refused to participate, due to travel factors or legal actions associated with head injury. Of the 58 remaining participants, 4 children were excluded due to limited competence with English, 1 child remained in a vegetative state for the 12-month follow-up period, and thus was unable to be tested, and 4 children were evaluated acutely, but were unwilling to attend for 12-month review. Results presented in this paper represent test results only for children who completed both acute and 12-month evaluations.

Measures

Preinjury screening

A. *Demographic–medical questionnaire*: Data were collected on each child's medical and developmental history, parental education and occupation, and family constellation. SES was coded using Daniel (1983), which rates parent occupation on a 7-point scale, where a high score represents low SES. For head-injured children, during inpatient stay, medical records were reviewed daily and details of GCS, length of coma, neurological abnormalities, and surgical interventions were recorded.

B. *Vineland Adaptive Behavior Scale (VABS; Sparrow et al., 1984)*: This scale has a questionnaire format that provides information on a child's level of adaptive func-

Table 1. Injury characteristics of head-injured sample

	Groups	
Injury characteristic	Mild–moderate HI ($N = 32$)	Severe HI ($N = 17$)
Age at injury (years); *M* (*SD*)	4.80 (2.02)	5.31 (1.85)
GCS (on admission)*; *M* (*SD*)	11.28 (3.48)	4.80 (1.52)
GCS (24 hr)*; *M* (*SD*)	13.10 (3.00)	6.14 (2.32)
Duration of coma *		
None	13	—
<1 day	19	3
1–7 days	—	5
>7 days	—	9
Neurosurgical intervention	11	10
Abnormal CT/MRI findings$^+$	20.0 (62.5%)	17 (100.0%)
Neurological abnormalities$^+$	9 (28.0%)	11 (64.7%)
Cause of injury		
MCA (passenger)	5	6
MCA (pedestrian/cyclist)	6	7
Fall/blow	19	2
Other	2	2

$^+p < .05$, $^*p < .001$.
GCS = Glasgow Coma Scale.
MCA = Motor car accident.

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tion, based on parental perceptions. In this study, the parent interview version of the scale was administered to provide information in three domains: communication, daily living, and social skills. A Total Adaptive Behavior score was also derived. For each of these areas standard scores were calculated ($M = 100$, $SD = 15$).

C. *Personality Inventory for Children (PIC; Lachar, 1992)*: This questionnaire was completed by parents to provide a measure of children's preinjury behavioral functioning. The revised format version was employed, which included 131 items for which parents respond either "true" or "false." Four factors are derived from the scale: *Factor I*: Undisciplined–Poor Self-control; *Factor II*: Social Incompetence; *Factor III*: Internalization–Somatic Symptoms; and *Factor IV*: Cognitive Development. A *Lie Scale* is also compiled on the basis of these items. Factor scores have a mean of 50 and standard deviation of 10 points, with scores greater than 70 considered to represent behavioral difficulties of clinical significance.

D. *Family Functioning Questionnaire (FFQ; Noller, 1988)*: This 68-item questionnaire was used to measure several hypothetical dimensions of family functioning, including adaptability, cohesion, family style, encouragement of autonomy, and communication. Each item was rated on a 6-point scale ranging from 1 = *totally agree* to 6 = *totally disagree*. Three factors are derived from the questionnaire: *conflict* (scored out of 60 points), *intimacy* (scored out of 72 points), and *democratic parenting style* (scored out of 30 points). For each factor, a higher score reflects more of that characteristic reported by families.

Child evaluations: Acute and 12 months

Intellectual evaluation. The Wechsler Preschool and Primary Intelligence Scale–Revised (WPPSI–R; Wechsler, 1989); the Wechsler Intelligence Scale for Children–III (Wechsler, 1992); or the Bayley Scales of Infant Development (Bayley, 1969) were administered, depending on the age of the child.

Expressive language.

Expressive One-Word Picture Vocabulary Test (EOWPVT; Gardner, 1979): This task measures a child's ability to provide names for pictorial stimuli. Standard scores ($M = 100$, $SD = 15$) were calculated, and these were included in analyses.

Bus Story (Renfrew, 1995): This test aims to investigate children's expressive language skills. Children are shown a picture and told a simple story about what is happening in the picture. Children are then required to retell the story in their own words. Age equivalent scores are derived for story content (*information*) and length, on the basis of instructions provided in the test manual, and these were used in analyses.

Verbal Fluency (McCarthy, 1972): Children are required to name items in each of four categories: things to eat, animals, things to wear, and things to ride. There is a 20-s time limit for each category. The total number of correct responses is calculated and an age equivalent score is obtained.

Receptive language.

Peabody Picture Vocabulary Test–Revised (PPVT–R; Dunn & Dunn, 1981): This task evaluates children's receptive skills for single words, with items graded in order of difficulty. Standard scores ($M = 100$, $SD = 15$) were employed in statistical analyses.

Test of Auditory Comprehension of Language–Revised (TACL–R; Carrow-Woolfolk, 1985): This measure includes a number of subtests that tap aspects of language comprehension. Deviation quotients ($M = 100$, $SD = 15$) were calculated and included in analyses.

Memory.

Rivermead Behavioral Memory Test for Children: (RBMT; Wilson et al., 1991): This is a measure derived to tap impairments of everyday memory in young children. While the test was derived for use with children age 5 years and older, it was administered to all children in the study, regardless of age. It includes 10 subtests that measure aspects of verbal and visual memory. A standard score is obtained for each subtest: 0 (*impaired*), 1 (*borderline*), or 2 (*normal*). These standard scores have been age-normed, and are summed to obtain a total score. For the present study, results from only 8 of the 10 subtests were included in analyses, as the remaining subtests (Appointments, Story–delayed) were observed to be too difficult for younger children. However, total scores reflect the reduced number of subtests, with a score of 14 to 16 categorized as *normal*, 10 to 13 as *borderline*, and zero to 9 as *impaired*.

Numerical Memory I (McCarthy, 1972): This task is a measure of auditory span, requiring the child to repeat strings of digits of increasing length. Raw scores were employed for purposes of statistical analysis.

Tapping Test (McCarthy, 1972): This task taps visual span, and requires the child to tap a series of spatial sequences of increasing complexity. Raw scores were employed for purposes of statistical analysis.

Story Recall (Anderson et al., 1995a; adapted from Christensen, 1979): A verbal learning task requiring children to recall stories. Two stories are read to the child, each including 21 content items. After each story, the child is instructed to retell the story in his or her own words. Recall (that is, number of content items recalled) is summed across the two stories, with a maximum possible score of 42 points.

Spatial Learning Test (Anderson et al., 1995a; adapted from Lhermitte & Signoret, 1972): This task measures spatial learning skills. Children are required to learn a spatial array of nine pictures, arranged in a 3×3 configuration on a wooden board. The nine stimuli are presented sequentially and placed on the board for the child to learn. The stimuli are then re-presented, and children are asked to correctly place each. Scores derived reflect the number of trials taken for the child to place all nine stimuli correctly.

Procedure

Children were enrolled in the study during initial hospital admission. Families were given a detailed description of the study and asked to provide written consent, consistent with hospital ethics procedures. At that time parents completed the demographic questionnaire, the VABS (Sparrow et al., 1984), the PIC (Lachar, 1992), and the FFQ (Noller, 1988), based on the child's preinjury abilities. The VABS was re-administered at 6 months postinjury.

Children were evaluated at two stages: acutely and 12 months postinjury. Acute assessment was conducted once acute neurological dysfunction–posttraumatic amnesia had resolved; thus there was some variability in the timing of this assessment (time lapse between injury and acute assessment from 0–3 months). Assessment occurred over two sessions, each lasting approximately 1 hr. Intellectual assessment was conducted in the initial session, with the remainder of the test procedures administered in a separate session, after a break. Assessments were performed on an individual basis by a qualified child psychologist and speech pathologist.

Due to the wide age range of the sample, children of different ages were administered different subgroups of the child evaluation battery described above. Language and memory measures were administered to all children, regardless of age. Where standardized scores were unavailable for younger children, raw scores were employed in statistical analyses.

For intellectual evaluations, at the acute assessment the Bayley Scales were administered to 10 children, the WPPSI–R to 41 children, and the WISC–III to 22 children; at 12-month follow-up the Bayley Scales were conducted with 3 children, the WPPSI–R with 34 children, and WISC–III with 37 children. While most children ($N = 52$) were administered the same intellectual measure on both occasions, 7 children were assessed on the Bayley Scales at acute evaluation and the WPPSI–R at 12 months, and 14 children received the WPPSI–R acutely and the WISC–III at 12 months.

To evaluate the possible impact of inclusion of multiple tests for the measurement of intellectual abilities, some preliminary analyses were conducted. Comparisons were made between mean performances of children for whom test procedures changed from T_1 to T_2 ($N = 21$) with those for whom tests remained the same ($N = 52$). Using the total sample and analyzing Full Scale IQ scores (FSIQ: FSIQ for WPPSI–R, WISC–III; MDI for Bayley Scales) for children receiving the same tests *versus* those receiving different tests, no differences were detected between the two groups either at acute evaluation or 12-month evaluation. Similarly, when the sample was divided according to both injury severity and tests conducted, no differences were detected with respect to FSIQ scores. These results suggest that the change in FSIQ scores from T_1 to T_2 was not differentiated on the basis of the tests administered.

In addition, correlational analyses were performed to determine whether test–retest correlations were similar for the two groups. Again FSIQ scores were employed in analyses. For children receiving the same measure at T_1 and T_2, test–retest correlations were high ($r = .93$, $p < .001$). In contrast, for those receiving different IQ measures, while correlations remained robust ($r = .74$, $p < .001$), they were significantly lower.

Statistical Analysis

The three groups (severe HI, mild–moderate HI, controls) were compared on preinjury and psychosocial measures to identify group differences that might influence postinjury performance. Repeated measures ANOVAs (Group $\times$ Time) were conducted to examine the association between injury severity and changes in test performance from acute to 12-month assessments. Separate analyses were performed for each domain: intellectual ability, language, and memory functioning. Where raw scores or age equivalent scores were employed in analyses, age at T_1 was included as a covariate in analyses. Similar analyses were performed for the VABS, preinjury and 6-month postinjury measures. Multiple regression was employed to determine predictors of outcome 12 months postinjury. Independent variables entered into these analyses included 24-hr GCS (injury severity), VABS (preinjury ability), FFQ parenting style (family functioning), SES, and age at injury. Correlations among these variables were established prior to performing regressions, to examine potential multicollinearity among predictors.

Where data were missing for individual test measures, usually due to the child's inability to complete the task, this is acknowledged by including specific sample sizes in appropriate tables.

RESULTS

Demographic and Preinjury Screening Variables

As illustrated in Table 2, there were no differences across the groups for sex and age at initial testing. Similarly, no significant group differences emerged for SES or family structure. For the Personality Inventory for Children, no preinjury group differences were identified for any of the four factors, or for the Lie Scale. However, a relatively small proportion of children sustaining severe HI came from intact family units. Analysis of family functioning indicated no group differences with respect to parenting style or family intimacy, but greater family conflict was reported for the mild–moderate HI group [$F(2,35) = 3.17$, $p < .05$]. Finally, preinjury VABS scores were consistent across the three groups [$F(2,54) = 0.82$, ns], indicating no significant preinjury group differences in adaptive abilities.

Comparison of Preinjury and Postinjury VABS Scores

As previously noted, preinjury VABS scores were essentially equivalent across groups. At 6 months postinjury, while

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Table 2. Demographic characteristics of sample

Characteristic	Head-injured children: Severe	Head-injured children: Mild–moderate	Noninjured controls
Number of participants	17	32	24
Sex (number male)	10	17	10
Age at initial testing (years); *M* (*SD*)	5.51 (1.88)	4.87 (1.99)	5.63 (1.83)
Socioeconomic status *M* (*SD*)	4.47 (0.96)	4.17 (1.04)	3.97 (0.88)
Personality Inventory for Children			
I. Undisciplined/poor self-control	56.18 (15.16)	58.52 (17.03)	61.50 (19.43)
II. Social Incompetence	53.72 (16.90)	52.20 (15.86)	51.00 (9.70)
III. Internalization/Somatic symptoms	55.55 (23.73)	58.12 (19.55)	58.06 (13.09)
IV. Cognitive Development	61.36 (24.26)	61.52 (17.87)	49.50 (11.10)
Family unit: % two-parent families	60.0	81.0	87.0
Family Functioning Questionnaire			
Conflict *M* (*SD*) $^{+}$	31.71 (9.18)	23.41 (6.47)	28.57 (9.10)
Intimacy *M* (*SD*)	60.14 (8.69)	66.52 (5.32)	65.21 (5.85)
Democratic Parenting Style *M* (*SD*)	35.14 (7.60)	39.11 (5.30)	41.71 (4.51)

$^{+}p < .05$.

the mean VABS scores all fell within the average range, there was a trend for poorer adaptive skills to be associated with more severe HI. These results are illustrated in Table 3. Repeated measures MANOVA identified a significant main effect for time for the Total VABS score [$F(42,1) = 10.63$, $p < .05$], and a trend towards a group effect [$F(42,2) = 2.69$, $p < .07$], with a decrease in adaptive abilities for all groups from T_1 to T_2, and the deterioration of greater magnitude for the head-injured groups. The individual domains of the VABS were also investigated. While not all domains registered significant results, there was a consistent trend for severe HI to be associated with poorer scores postinjury. A significant main effect of time was reported for Socialization [$F(40,1) = 7.55$, $p < .01$], with all groups showing reduced development over time for this domain. No significant effects were identified for Communication or Daily Living Skills, although less dramatic trends were suggested by the data. Results indicate the expected dose–response relationship for severity of injury, with more severe HI associated with poorer scores on measures of adaptive behavior, even up to 6 months postinjury.

Intellectual Recovery

Table 4 provides results for IQ measures at acute and 12-month evaluations. Repeated measures ANOVA (Group × Time) identified a significant main effect of group [$F(63,2) = 3.65$, $p < .05$] and time [$F(63,1) = 4.88$, $p < .05$] for total IQ (i.e., FSIQ for WPPSI–R, WISC–III; MDI for Bayley Scales), with the severe HI group achieving lowest scores overall, as well as a decrease in scores from T_1 to T_2. For children administered the WPPSI–R or WISC–III at acute and 12-month evaluations, Verbal IQ and Performance IQ scores were also investigated. No significant group or time differences were identified for Verbal IQ, although the severe HI group did demonstrate a drop in scores not evident for the other two groups. For Performance IQ, main effects were found for both group [$F(57,2) = 7.63$, $p = .001$] and time [$F(57,1) = 12.10$, $p = .001$], but there were no significant interaction effects identified. This pattern of findings indicates that young children sustaining severe HI perform consistently more poorly than those sustaining mild to moderate injuries, or healthy controls, on overall intel-

Table 3. Vineland adaptive behavior scores: Preinjury and postinjury indices

Domain	Severe HI ($N = 17$) Preinjury *M* (*SD*)	Severe HI ($N = 17$) 6 months *M* (*SD*)	Mild–Moderate HI ($N = 32$) Preinjury *M* (*SD*)	Mild–Moderate HI ($N = 32$) 6 months *M* (*SD*)	Noninjured controls ($N = 24$) Preinjury *M* (*SD*)	Noninjured controls ($N = 24$) 6 months *M* (*SD*)
Communication	105.7 (16.1)	98.8 (18.5)	98.37 (23.9)	100.5 (16.4)	110.4 (13.5)	110.0 (15.6)
Daily Living	100.4 (21.0)	93.0 (23.0)	106.2 (12.8)	104.9 (16.0)	111.6 (13.9)	112.8 (20.0)
Socialization[b]	111.5 (12.2)	99.8 (15.9)	110.8 (16.7)	103.7 (21.1)	114.4 (16.8)	110.9 (15.2)
Total[b]	110.0 (17.2)	95.2 (22.7)	109.9 (16.7)	103.5 (19.2)	115.9 (15.7)	114.5 (17.8)

[b]Significant main effect of time.

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Table 4. IQs for severity groups at acute and 12-month postinjury evaluations

		Severe HI		Mild–Moderate HI		Noninjured controls	
IQ measure	*n*	Acute M (*SD*)	12 months *M* (*SD*)	Acute *M* (*SD*)	12 months *M* (*SD*)	Acute *M* (*SD*)	12 months *M* (*SD*)
Verbal IQ	63	89.6 (17.5)	83.6 (19.1)	98.3 (10.4)	99.7 (11.9)	99.3 (16.3)	98.7 (14.1)
Performance IQ[a,b]	63	83.2 (20.9)	85.2 (21.0)	96.4 (11.1)	100.4 (11.8)	107.3 (15.5)	108.5 (19.5)
Full Scale IQ[a,b]	73	87.7 (19.9)	85.1 (20.0)	99.3 (12.9)	101.3 (12.2)	102.4 (15.5)	103.7 (16.7)

[a]Significant main effect of group.
[b]Significant main effect of time.

lectual ability, thus supporting a dose–response relationship for injury severity. Further, there is no clear evidence for recovery over time following HI, with changes in results related to time since injury being relatively consistent across all groups, and possibly due to a practice effect, rather than to recovery of function.

Language Skills

Results on language tests were also found to be related to severity of injury; results are provided in Table 5. Repeated measures ANOVA (or ANCOVA) indicated a significant main effect of group for both expressive skills [EOWPVT: $F(2,59) = 4.34$, $p < .05$; Verbal Fluency: $F(2,59) = 3.70$, $p < .05$; Bus Story: Length: $F(2,59) = 3.64$, $p < .05$] and receptive skills [PPVT–R: $F(2,59) = 4.70$, $p < .01$; TACL–R: $F(2,59) = 4.87$, $p < .01$], with more severe injury associated with poorer scores for all measures. A main effect of time was found for the EOWPVT [$F(1,59) = 8.84$, $p < .01$], Verbal Fluency [$F(1,59) = 7.02$, $p < .01$], and TACL–R [$F(1,59) = 4.81$, $p < .05$], reflecting improvement over time on these measures for all groups. No significant interaction effects were identified on language measures, indicating no substantive evidence of differential improvement or recovery of skills in the 12 months postinjury for HI children. However, there was a nonsignificant trend for greater improvement in scores from T_1 to T_2 for the severe HI group, with scores remaining relatively stable for the other two groups, as shown in Table 5.

Memory Skills

For memory tests, with the exception of the RBMT, raw scores were employed in analyses, as age-standardized scores were not available for these measures over the age range included in the study. ANCOVAs were conducted for these variables, with age at T_1 employed as a covariate. Scores for memory tests are presented in Table 6. Analysis detected a main effect of group for the Tapping Test [$F(2,53) = 4.21$, $p < .05$] and Story Recall [$F(2,45) = 3.02$, $p < .05$], and a significant time effect was observed for the Tapping Test [$F(1,45) = 16.87$, $p < .0001$] and Numerical Memory [$F(1,45) = 6.34$, $p < .01$], reflecting expected de-

Table 5. Language test results at acute and 12-month postinjury evaluations

	Severe HI ($N = 16$)		Mild–Moderate HI ($N = 28$)		Noninjured controls ($N = 22$)	
Test measure	Acute *M* (*SD*)	12 months *M* (*SD*)	Acute *M* (*SD*)	12 months *M* (*SD*)	Acute *M* (*SD*)	12 months *M* (*SD*)
Expressive measures						
EOWPVT (standard score)[a,b]	85.8 (23.2)	94.8 (20.9)	105.8 (16.7)	109.3 (12.9)	98.5 (23.3)	97.3 (19.6)
Bus Story: information* (AE)	13.7 (8.2)	14.9 (10.7)	19.5 (10.7)	26.5 (11.1)	24.1 (9.7)	28.1 (11.5)
Bus Story: length* (AE)[a]	17.4 (13.8)	11.1 (8.9)	13.6 (10.5)	15.9 (11.3)	9.1 (2.6)	10.7 (3.9)
Verbal Fluency* (AE)[a,b]	5.1 (1.6)	5.6 (1.8)	5.9 (1.6)	6.2 (1.7)	6.2 (1.8)	6.5 (1.6)
Receptive measures						
PPVT–R (standard score)[a]	80.6 (22.8)	85.1 (18.3)	100.3 (12.7)	100.1 (15.2)	91.7 (30.1)	92.6 (29.9)
TACL–R (deviation quotient)[a,b]	79.1 (20.9)	87.6 (15.4)	99.0 (15.1)	101.5 (15.2)	97.3 (30.6)	97.4 (18.2)

Note. AE = age equivalent scores.
*For these variables ANCOVA was conducted, with age at T_1 as covariate. ANOVA was employed for all other analyses.
[a]Significant main effect of group.
[b]Significant main effect of time.

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Table 6. Memory test results at acute and 12-month evaluations

	Severe HI ($N = 9$)		Mild–moderate HI ($N = 21$)		Noninjured controls ($N = 19$)	
Test measure	Acute *M* (*SD*)	12 months *M* (*SD*)	Acute *M* (*SD*)	12 months *M* (*SD*)	Acute *M* (*SD*)	12 months *M* (*SD*)
RBMT: total score	13.0 (4.8)	12.5 (4.5)	14.1 (3.1)	15.5 (1.2)	13.6 (3.5)	15.5 (1.1)
Numerical Memory*: raw score[b]	6.0 (1.0)	7.7 (1.5)	5.8 (1.3)	7.6 (2.4)	5.7 (1.3)	6.8 (1.4)
Tapping Test*: raw score[a,b]	3.3 (2.9)	5.7 (0.6)	5.0 (1.8)	5.6 (0.8)	4.7 (1.3)	5.0 (1.2)
Story Recall*: no. items recalled[a]	14.0 (7.1)	16.7 (11.0)	14.7 (9.2)	18.2 (6.6)	13.6 (6.4)	21.0 (8.2)
Spatial Learning*: trials to criteria	5.0 (4.4)	4.5 (3.5)	3.7 (1.3)	3.8 (1.9)	4.7 (2.6)	3.8 (2.6)

*For these variables ANCOVA was conducted, with age at T_1 as covariate. ANOVA was employed for other analyses.
[a]Significant main effect of group.
[b]Significant main effect of time.

velopmental gains in raw scores for these measures. For the RBMT, age-standardized total scores were evaluated. No main effects, and no interactions were identified. There was a nonsignificant trend for a change in these scores over time [$F(1,49) = 3.77$, $p = .06$], with the severe HI group showing a small decrease in performance, and mild–moderate HI and control groups improving from T_1 to T_2. When interpreting these RBMT results, it is relevant to note that a greater proportion of children in the severe HI group were unable to complete the RBMT, and thus their results were excluded from analyses. Such a systematic loss of data may bias results against detecting a meaningful group difference on this measure.

Predicting Outcome Following HI

To investigate predictors of outcome at 12 months post-HI, a series of multiple regressions was conducted on summary standardized outcome measures including Full Scale IQ, Verbal IQ, Performance IQ, EOWPVT, TACL–R, PPVT–R, and

Table 7. Significant predictors of outcome at 12-months postinjury

	Outcome measures					
Predictor variables	VIQ	PIQ	FSIQ	EOWPVT	TACL–R	RBMT: Tot.
GCS 24 hr						
Beta	.31	.45	.38	.33	.32	.31
t value	2.11	2.74	2.72	1.96	1.86	1.71
p	.04	.01	.01	.06	.07	.09
AAI						
Beta	.06	−.02	−.05	.21	−.19	.53
t value	0.05	−0.16	−0.38	1.39	−1.19	3.16
p	ns	ns	ns	ns	ns	.004
Preinjury VABS						
Beta	.39	.27	.41	.08	.23	.09
t value	3.07	1.90	3.37	0.56	1.54	0.55
p	.004	.06	.001	ns	ns	ns
SES						
Beta	−.25	−.21	−.24	−.43	−.20	.11
t value	−1.92	−1.34	−1.88	−2.76	−1.24	0.64
p	.06	ns	ns	.01	ns	ns
FFQ						
Beta	.16	−.01	.09	.14	.09	.23
t value	1.08	−0.06	0.60	0.82	0.53	1.21
p	ns	ns	ns	ns	ns	ns
R^2	.52	.41	.55	.41	.41	.44

GCS: Glasgow Coma Score; AAI: Age at injury; VABS: Vinelard Adaptive Behavior Scale; FFQ: Family Functioning Questionnaire; VIQ: Verbal IQ; PIQ: Performance IQ; FSIQ: Full Scale IQ; EOWPVT: Expressive One-Word Picture Vocabulary Test; RBMT: Rivermead Behavioral Memory Test; TACL-R: Test of Auditory Comprehension of Language-Revised.

RBMT. Predictors of outcome employed in the analyses were 24-hr GCS score, age at injury (AAI), preinjury VABS score, SES, and FFQ. Correlational analyses were conducted with these predictors, with significant correlation coefficients obtained between VABS preinjury score and SES only ($r = -0.37$, $p < .01$). Results from subsequent regression analyses are summarized in Table 7. Severity of injury was found to be the most consistent predictor of 12-month outcome, with GCS (24 hr) significantly associated with VIQ, PIQ, and FSIQ. Further, this relationship approached significance for all other outcome measures. Age at injury was also identified as related to outcome, but only for memory measures (RBMT total). Not surprisingly, preinjury VABS total scores were predictive of intellectual scores at 12-month follow-up, and SES was related to aspects of linguistic ability (VIQ, EOWPVT). Family functioning was not a significant predictor for any of the intellectual, language, or memory variables.

This pattern of results points to the importance of injury-based, developmental, and premorbid factors for early functional outcome following HI in young children. Family functioning and SES were less significant predictors for any of the outcome variables. However, it should be acknowledged that the proportion of variance accounted for by these regression equations is relatively low, suggesting that other, untested factors may also be associated with outcome.

DISCUSSION

The aim of this study was to describe the nature of deficits exhibited by children sustaining HI in early childhood, to document changes in the 12 months postinjury, and to identify predictors of early outcome. To do this three groups were examined: severe HI, mild–moderate HI, and noninjured controls. The study was designed to compare groups that were similar preinjury on a number of critical variables including age at injury, adaptive functioning, behavioral status, SES, and family functioning. Thus, group differences identified postinjury could be associated with effects of HI.

Consistent with previous research, our findings supported a relationship between injury severity and neurobehavioral functioning. Postinjury, significant group differences were evident in a range of cognitive domains, including intellectual ability and linguistic skill, with more severe HI associated with poorer test performance. This pattern of deficits was present in the acute recovery phase, and maintained at assessments conducted 12 months postinjury. In contrast to the finding of significant early recovery of function in adults and older children, this picture of persisting impairment did not support the presence of similar recovery in young children. Specifically, statistical analyses did not reveal any Group $\times$ Time interaction effects, which would be expected if differential improvements in skills were occurring for head-injured children. Rather, when performance increments were detected between acute and 12-month evaluations, they were generally consistent across groups, and most likely represented either practice effects (for age-standardized measures) or expected developmental gains (for tests scored as raw scores or age equivalents). Finally, 12-month outcomes were largely predicted by injury severity, with age at injury and preinjury abilities associated with outcome for specific skills, with surprisingly little evidence for any substantial impact of psychosocial factors.

In the acute postinjury stages, subjective parental perceptions of adaptive functioning, as measured by the VABS, were associated with injury severity. As might be expected, comparison of preinjury and postinjury parental reports identified a trend to deterioration in adaptive functioning for children sustaining HI, while parents of noninjured children reported expected developmental gains for their children. For individual adaptive domains, this pattern of injury-related deterioration was most marked within the Socialization domain, with similar, nonsignificant trends evident for Daily Living Skills and Communication. Injury severity was also related to children's postinjury performances on standardized psychometric measures. In the initial three months postinjury, mean group performances showed a definite dose–response relationship. Severe HI was associated with impairments in intellectual ability, expressive language, and receptive language. As expected the impact of mild–moderate HI was less dramatic, with mean scores for this group closer to that of noninjured controls, and generally within age-based expectations.

Despite some evidence of increases in test scores, findings failed to provide support for any substantial recovery of function from the acute stage to 12 months postinjury, with group differences persisting over time on most tasks. For tasks tapping well-learned knowledge or basic language skills (Verbal IQ, PPVT–R), HI children showed impaired, but relatively stable results over time, providing no evidence for recovery-related gains. At 12 months postinjury, children sustaining severe HI continued to exhibit significant receptive and expressive language difficulties. For those in the mild–moderate HI group, small, nonsignificant increments in scores were noted, in contrast to control results, which remained largely unchanged across the two assessments. Significant gains were identified on some language measures. However, these improvements were consistent across all groups, and appeared unrelated to HI. Further consideration of these results showed that increments occurred either on standardized measures susceptible to practice effects (e.g., Full Scale IQ, Performance IQ) or for measures where raw scores were employed, and where increments could be interpreted as related to expected developmental gains (e.g., Verbal Fluency, Numerical Memory, Tapping Test). In neither instance could changes in performances be attributed to recovery. Such findings emphasize the importance of including a noninjured control group when using serial testing to investigate recovery processes. Finally, memory measures showed a nonsignificant trend for deterioration over time, with more severely injured children achieving more impaired scores at 12-month assessment, in keeping with the notion of "emerging deficits" following childhood brain insult (Anderson, 1988; Banich et al., 1990).

The final aim of the study was to identify predictors of outcome at 12 months postinjury. A number of candidates were considered as possible prognostic indicators, based on previous research findings. Injury severity, age at injury, preinjury adaptive functioning, SES, and family functioning were all examined. However, only one of these factors was found to have significant predictive value: greater injury severity, as measured by 24-hr GCS, was consistently predictive of poorer performance. Specifically, more severe injuries were associated with poorer outcome on summary IQ, language, and memory measures.

Younger age at injury was a less consistent predictor of 12-month outcome, but was closely linked to reduced memory capacity. While the age-related findings from the study are modest, they are inconsistent with notions of cerebral plasticity (Lenneberg, 1967; Smith, 1983), showing that recovery is less dramatic than might be expected in the younger age range. Further, even within the narrow age band employed in this study, earlier age at injury was associated with poorer outcome, particularly in the domain of memory. Interestingly, such skills are reported to be immature, but developing rapidly during the early childhood period. Dennis's (1989) hypothesis that such skills may be particularly vulnerable to the impact of early cerebral insult is supported by our findings. However, several methodological issues may have affected the investigation of this variable. First, the age range of the sample is restricted to young children, who may be particularly vulnerable to the effects of cerebral insult. Previous studies have noted that it is difficult to differentiate age effects in this lower range, with all children similarly at risk (Smibert et al., 1996). Further, there was a trend for younger, more severely injured children to experience difficulties coping with test demands. The conservative decision to exclude such data, rather than to code it to represent the actual level of difficulty exhibited, may result in a systematic bias that acts against establishing the actual magnitude of impairment associated with these parameters within the sample.

The lack of impact of psychosocial factors in the present sample is somewhat surprising. It may be that, as early as 12 months postinjury, the effect of injury severity is of such magnitude that it masks other possible effects. Alternatively, it may be that the use of preinjury estimates of family functioning do not tap the relevant problems. Certainly, the psychosocial characteristics of the head-injured children included in this study were not suggestive of substantial preinjury family pathology, in keeping with findings from other recent studies (Donders, 1992; Prior et al., 1994). It may be that the family-related factors that are important for prognosis are only evident postinjury. Consistent with this suggestion, the effects of psychosocial factors have been argued to be cumulative, and may only become apparent with increasing time since injury. Such findings have been documented in other pediatric disorders that occur in early childhood; for example, meningitis and prematurity (Breslau, 1990; Taylor et al., 1992). In studies of school-age children, there is evidence that marital relationships fail in the years postinjury, as family isolation increases when parents are required to remain at home to care for their impaired child, and are thus less likely to socialize because of the social problems experienced by the child (Perrot et al., 1991, Taylor et al., 1995). No research is available relating specifically to very young children, but it may be hypothesized that, given their greater dependence on the family environment, younger children may be more susceptible to these effects in the long-term. However, further follow-up of the present sample is needed to evaluate such statements

One of the problems in the field of pediatric HI relates to difficulties in attributing postinjury impairments to injury-related variables. Authors have suggested that such interpretations may be invalid, due to the "unrepresentative" nature of the pediatric HI population. It has been argued that children sustaining HI are more likely to come from socially disadvantaged families, and have higher risk of premorbid learning and behavioral deficits. If such sample biases do exist then they may result in an overestimation of impairments related to HI. Thus, to attribute postinjury deficits specifically to HI, clinical and comparison groups should ideally be equivalent for psychosocial and ability variables preinjury. Any differential performances postinjury may then be more reliably related to injury factors. In the present study, we were able to establish such group equivalence, with no group differences identified for SES, overall family functioning, preinjury adaptive and behavioral skills. Such a design enabled investigation of changes in performance for both noninjured and HI children, teasing out important factors such as practice effects and, for measures where poor normative data were available, expected developmental gains. When these crucial considerations were incorporated into interpretations, a disappointing lack of recovery was evident. In fact, for no measure was there an indication of significant improvement in performance, over and above that observed for noninjured children.

The present study is limited by a number of methodological problems. First, sample size is relatively small, and limits the statistical power of analyses. It may be that, with a larger sample, some of the trends for recovery in the HI groups might have reached statistical significance. Second, and common to many longitudinal developmental studies, is the problem of usage of multiple test measures. In the present study, three separate measures of intellectual ability were used, and while correlations across these measures were robust, it is difficult to determine the subtle impact of these variations in methodology. The design does not allow for investigation of psychometric variability either within or across tests. Additionally, for very young children (particularly those younger than 2.5 years), tests tapping skills known to be vulnerable to the impact of HI (e.g., memory, language) are scarce, and age-related norms are commonly unavailable. Further, the capacity of the younger children to complete these tasks was more variable, leading to more missing data for younger children. Such systematic problems for younger children leads to difficulties in interpreting age at injury–severity effects in the sample.

In summary, and as expected from the adult literature, severity of injury is closely related to cognitive outcome following HI, with more severe injuries associated with poorer IQ, impaired linguistic functions, and emerging memory deficits. Further, recovery profiles following HI in early childhood do not conform to adult models, but are dependent on severity of injury. Our results indicate that, while children sustaining less severe injuries show some evidence of early recovery, such improvement is not observed following severe HI. Finally, early outcome following preschool HI is more strongly associated with injury-related factors, including severity and age at injury, with premorbid characteristics and psychosocial factors less influential. To date, follow-up data on our sample are only available to 12 months postinjury. With longer duration of follow-up it is possible that a pattern of functional recovery may emerge. Similarly, with time, the importance of injury-based factors may diminish, with psychosocial parameters playing a greater role.

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