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A prospective analysis of the recovery of attention following pediatric head injury

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Abstract

Little is known about specific attentional sequelae following a closed head injury, their pattern of recovery or their interaction with ongoing development. The present study examined attentional abilities in a group of children who had sustained a mild, moderate, or severe head injury. Results showed that the severe head injury group exhibited greater deficits on a number of attentional measures at acute and 6 months postinjury phases, in comparison to children in the mild and moderate head injury groups. Specifically, deficits were most evident on timed tasks where speed of processing was an integral component. Difficulties persisted to at least 6 months postinjury and so may lead to cumulative deficits over time. (*JINS*, 1999, *5*, 48–57.)

Keywords: Head injury, Children, Attention, Recovery

INTRODUCTION

While there is difficulty in accurately establishing the incidence of pediatric head injury (HI), some rough estimates indicate that 180 per 100,000 children sustain a head injury each year (Kraus, 1995). It has been reported that more than 1,000,000 children in the United States sustain closed head injuries annually and that 1/6 of these injuries are sufficiently serious to result in hospital admission (Eiben et al., 1984), with such injuries most frequent in the birth to 24-year age range (Kraus, 1987). There is a growing literature addressing the global intellectual, physical, and behavioral consequences of these injuries; however there is less known about specific attentional sequelae, the pattern of their recovery and their interaction with ongoing development.

Findings from studies of adult HI suggest that, while attentional deficits may be most severe in the acute stages postinjury, persisting attentional and speed of processing deficits are also common. According to Wood, impairment of the information processing system of the brain after HI is inevitable (Wood, 1988). He argued that HI may limit attentional capacity and reduce the extent to which attention can be divided across stimuli and affect the ability to shift one's mode of thinking as the demands of a task change, resulting in slower and less reliable processing, poorer responses and an interference in other areas of neuropsychological functioning and educational skills.

More recently, it has been argued that attention is not a unitary process and a number of models have described it as an integrated system, both cognitively and physiologically (Cooley & Morris, 1990; Halperin, 1991; Mirsky et al., 1991; van Zomeren & Brouwer, 1994) involving a number of separate, though not independent components. According to Mirsky and associates (Mirsky et al., 1991) attention can be broken into the following components: (1) sustained attention or vigilance, that is, the capacity to maintain arousal and alertness over time; (2) the ability to select target information while ignoring irrelevant stimuli, and to differentially process simultaneous sources of information; (3) the ability to change attentive focus in a flexible and adaptive manner. Speed of processing, or the rate at which activities may be completed, is also incorporated into Mirsky's system, and is considered to underpin the efficiency of the system.

The attentional system is thought to be subsumed by a number of cerebral systems including the brainstem, midbrain structures, temporal, parietal, and frontal regions. Mirsky et al. (1991) argue that each area is related to a specific attentional component. The model suggests that damage or dysfunction to any one of these regions can lead to specific

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deficits in attentional ability or speed of processing, restricting the efficiency of the whole system. Of importance, it is these areas that subserve attentional and information processing functions, that have been observed to be particularly vulnerable to damage occurring in a closed head injury; therefore it is not surprising that deficits emerge at the acute or later stages (Walsh, 1978).

Van Zomeren and Brouwer (1994) describe general disruption to attention and information processing following adult HI, citing clinical reports of forgetfulness, poor ability to concentrate, and a slowness in response. However, others argue that deficits may be more specific. In particular, a number of studies have found deficits in speed of processing and motor responses, with otherwise intact attentional capacities (Brouwer et al., 1988; Murray et al., 1992; Ponsford & Kinsella, 1992). These results have been supplemented by others which report that, in addition to slowed responses, adults suffering from HI present with a pattern of inconsistent performances that further complicate diagnosis and treatment in this group (Stuss et al., 1989).

Thus, the pattern of attentional and speed of processing deficits observed following adult HI is reasonably well documented. However, knowledge pertaining to adult HI is not necessarily generalizable to the pediatric population. Some authors have argued that children recover better from HI, citing protective physiological factors including the relative flexibility of the child's skull, the lower frequency of intracranial hematomas, and the plasticity of the developing brain (Lenneberg, 1967). Others argue for poorer outcome in young children due to the immaturity of the central nervous system, in particular the frontal lobes and white matter, and resultant impact on cognitive skills essential for normal development including attention, memory, and adaptive skills (Anderson & Moore, 1995; Anderson & Pentland, in press; Dennis, 1989; Dennis et al., 1995; Ewing-Cobbs et al., 1989; Gronwall et al., 1997).

To date, the study of sequelae from pediatric HI has tended to focus mainly on cognitive recovery and outcome (Ewing-Cobbs, et al., 1989; Fay et al., 1993; Goldstein & Levin, 1985). However, given the findings from adult literature, further investigation of attentional and information processing skills appears warranted. From a developmental perspective, these skills may be argued to be of particular importance during childhood. If such abilities are critical for the development of cognitive and neuropsychological systems, which in turn influence adaptive, social, and academic functioning (Cooley & Morris, 1990; Dennis et al., 1995), then deficiencies may have a significant impact on the child's development in the acute and long-term stages.

Despite the importance of attention in this younger age group, only a few studies have been reported. Timmermans and Christensen (1991) investigated 38 HI children, aged 5 to 16 years, and found evidence for impairments in sustaining attention, with selective attention skills intact. In contrast, Dennis and associates (Dennis et al., 1995) found that children and adolescents with a history of head injury performed poorly on a measure of vigilance and selective attention. Kaufman et al. (1993) also reported similar findings, noting that on the Continuous Performance Task, children with severe HI demonstrated significant difficulties sustaining attention. More recently, Anderson and Pentland (in press) have argued for a pattern of global attentional deficits following head injury sustained in childhood. They studied the attentional profiles of children who had sustained moderate to severe HI, and found that attentional and information processing deficits persist in the years postinjury, with greatest problems in the areas of speed of processing (which may be the deficit underlying poor results on sustained and focused attention tasks) and shifting attention. Interestingly, it is these impaired components of attention and information processing that are believed to continue to mature into late childhood and early adolescence (McKay et al., 1994), suggesting that childhood injury may interfere with their efficient development.

While research addressing attentional sequelae of pediatric HI is advancing, to our knowledge reported work has been limited to cross-sectional designs. There is very little empirical evidence regarding the possible recovery of these skills, and the interaction between attentional and speed of processing capacity and ongoing social and educational development. The aim of this study was to investigate attention and speed of processing deficits that occur as a result of pediatric HI. First, the longitudinal design of the study provided the opportunity to map recovery and development of these skills during the 6 months postinjury, with our prediction being that identified deficits would persist, and the degree of deficit would be related to injury severity. Second, by employing a range of measures, we have attempted to separate specific components of attention and speed of processing to determine whether any identified attentional deficits are of a generalized nature or are specific to a particular aspect of attention. Based on adult literature and limited pediatric findings, we hypothesized (1) that moderate and severe head injury would be associated with generalized attention and information processing deficits in the acute postinjury phase; and (2), that some recovery would occur over time, with more deficits in speed of processing and shifting attention at 6 months postinjury, reflecting the interaction between injury factors and ongoing development.

METHODS

Research Participants

The sample comprised 43 children who had sustained a documented HI, and represented consecutive admissions to the neurosurgery ward of the Royal Children's Hospital, Melbourne, between June 1994 and January 1996. Of these children 31 were male and 12 were female. Inclusion criteria were (1) aged between 8–12 years at time of injury; (2) documented evidence of closed head injury, including period of altered conscious state; (3) medical records sufficiently detailed to determine severity of injury; that is, including

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Glascow Coma Scale (GCS; Teasdale & Jennett, 1974), posttraumatic amnesia (PTA; length of time from accident until orientation to person, time, and place), and neurological and radiological findings. Exclusion criteria were history of neurological or developmental disorder, previous head injury, and documented learning or attentional disability.

HI children were categorized into severity groups on the following basis: (1) *mild HI* ($N = 13$): GCS on admission of 13–15, loss of consciousness (LOC) less than 1 hr, PTA of less than 24 hr, and no abnormalities on CT or MRI scans; (2) *moderate HI* ($N = 19$): GCS on admission of 9–12, LOC from 1–24 hr, and PTA from 1–7 days; abnormalities on CT or MRI; (3) *severe HI* ($N = 11$): GCS on admission of less than or equal to 8, LOC greater than 24 hr, PTA of greater than 7 days; abnormalities on CT or MRI. Implementation of these variables successfully categorized all 43 children. Tables 1 and 2 provide demographic and injury data for the sample.

As illustrated in Tables 1 and 2, the groups did not differ with respect to sex, socioeconomic status (SES), or family constellation. However, a significant difference was evident across the groups for age at injury, with the severe HI group being somewhat older [$F(2,40) = 3.62$, $p < .05$]. Time interval from injury to first assessment did not differ significantly across groups [$F(2,40) = 1.34$, $p = .27$], although the severe HI group recorded the longest delay, reflecting longer duration of coma and PTA. As expected, there were significant group differences on all medical variables, with the severe HI group presenting with most complications, apart from the number of fractures. Further, severe HI were mainly due to motor vehicle accidents. Of the children presenting with neurological signs in the moderate and severe groups, 1 child had a mild hemiperesis on the left side, 2 children presented with right sided weakness, 1 child was restricted to a wheelchair and had poor motor control, and 2 children experienced seizures postinjury.

Table 2. Injury and medical characteristics of sample

Characteristic	Mild HI ($N = 13$)	Moderate HI ($N = 19$)	Severe HI ($N = 11$)
Cause of injury			
MCA: Passenger (N)	1	1	3
MCA: Pedestrian (N)	1	3	7
Fall (N)	9	7	1
Blow (N)	2	8	0
Medical characteristics			
GCS: admission*: M, (SD)	14.1 (1.3)	11.4 (2.9)	5.8 (2.9)
GCS: 24 hr*: M, (SD)	15.0 (0)	13.3 (2.2)	7.7 (2.8)
Coma > 1 hr (N)	—	5	7
PTA > 1 day (N)	—	9	11
Abnormal CT/MRI (N)	—	15	11
Skull fracture (N)	3	10	8
Neurological signs (N)	—	7	8
Surgical intervention (N)	—	10	9

*$p < .01$.
MCA = motor car accident.

Measures

Preinjury questionnaires

A. *Epidemiological questionnaire*: This questionnaire documented parental occupations and educational level, family constellation, and medical and developmental history of the child. Socioeconomic status was recorded according to Daniel's Scale of Occupational Prestige (Daniel, 1983), where a low score reflects high occupational prestige. The scale ranges from 1.0 to 6.9.

B. *Medical questionnaire*: This questionnaire was based on data recorded in the child's medical record, including GCS scores, period of unconsciousness, duration of posttraumatic amnesia, neurosurgical interventions, neurological signs, and radiological results.

C. *Vineland Adaptive Behaviour Scale (VABS; Sparrow et al., 1984)*: This questionnaire was completed by parents, at the time of recruitment to the study, while the child was still in hospital. Parents were asked to describe their child's preinjury abilities. The VABS was readministered at 6 months postinjury to document changes to adaptive function associated with head injury. It provides a global measure of adaptive functioning, as well as scores for the domains of *communication*, *daily living*, *social skills*, and *motor skills*. Each domain is standardized, with a mean of 100 and a standard deviation of 15.

Table 1. Demographic characteristics of sample

Variable	Mild HI	Moderate HI	Severe HI
N	13	19	11
Number of males	9	14	8
Age at initial testing (years): M, (SD)	10.6 (1.6)	10.0 (1.5)	11.4 (1.2)
Time: Injury to testing (months): M, (SD)	1.3 (1.0)	1.4 (0.7)	1.9 (1.3)
Socioeconomic status: M, (SD)	4.3 (1.1)	4.3 (1.0)	4.4 (1.0)
Intact families (N)	10	14	8

*Daniel (1993)

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Child assessment

Intellectual measure: The Wechsler Intelligence Scale For Children–Third Edition (WISC–III; Wechsler, 1991) assessed general intelligence. Three scores were employed in analyses: Verbal (VIQ), Performance (PIQ) and Full Scale Intelligence Quotient (FSIQ).

Attentional measures: Several components of attention were investigated, as outlined in Mirsky's model (Mirsky et al., 1991).

1. *Sustained attention*: The Continuous Performance Task (CPT; modified version of Mirsky et al., 1991) was used to examine the ability to maintain performance over time as well as speed of information processing. In this computerized task stimulus letters were displayed for a duration of 500 ms with an interstimulus interval of 1.5 s. Task duration was 20 min, during which time 600 stimuli were presented. Children were initially given a trial run to ensure that they understood the requirements of the task. Two letters flashed on the screen and the child was given a target letter (e.g., 'c') on which to focus. The child was then shown a response box where the yellow "yes" button was to be pressed if a 'c' had flashed on the screen, and the blue "no" button if neither of the letters was a 'c.' Scores employed in the analysis were total correct score and total reaction time. Also investigated were the number of omission and commission errors, missed responses and impulsive responses (reaction time $<$ 200 ms). For each of these variables a total score was obtained, as well as scores for the first 5 min (Block 1) and last 5 min (Block 4) of the task, to enable further measurement of sustained attention.

2. *Selective attention*: Two tests were administered, each tapping visual selective attention and processing speed: (1) Letter Cancellation Test (LCT; Talland, 1965) for which the child was presented with a sheet of paper containing rows of letters and instructed to cross out all the 'C's and the 'E's as quickly as possible. The number of letters correctly cancelled in 1 min was recorded; and (2) Trail Making Test–Part A (Trails A; Reitan & Davison, 1974) where children were asked to join a series of numbers in order, under timed conditions, with time taken to completion being the variable employed in analyses.

3. *Shift*: Two measures were employed to tap these skills: (1) Trail Making Test–Part B (Trails B; Reitan & Davison, 1974). The child was asked to join consecutive alternating letters and numbers, requiring a shift from one sequence to another. Time taken for task completion was recorded; and (2) Contingency Naming Test (CNT; Taylor et al., 1992). This task has a number of components, each one increasing in difficulty level. The child is presented with a stimulus sheet displaying circles, squares, and triangles of different colours, with each stimulus including a color dimension and an internal and external shape. The first condition requires the child to name the color of each shape and the second condition to name the external shape. The third condition is more complex and involves implementation of two rules: (a) if the internal and external shapes are the same, state the color; (b) if the internal and external shapes are different, state the external shape. The fourth condition becomes more complex as some shapes have an arrow placed above them, and for these shapes the rule learned in Condition 3 is to be reversed, while for all other stimuli the correct response is as for Condition 3. This fourth condition was used in the analysis and was scored in terms of the time taken for task completion.

Procedure

Parents of children who met the selection criteria were invited to participate in the study. The research study was introduced and explained in detail and written consent was obtained, according to hospital ethics guidelines. Once the family had given consent for participation the appointment times were scheduled and the epidemiological questionnaire and the Vineland Adaptive Behavior Scale (Sparrow et al., 1984) were completed, based on preinjury status. During the acute stage (0–3 months postinjury) the total test battery was administered. The VABS and the attentional measures were then repeated at 6 months postinjury. All assessments were conducted by a qualified psychologist and took place over two 1-hr sessions. Order of test administration was fixed, with WISC III completed in one session and attentional measures in the second session.

Statistical Analysis

The three groups (mild, moderate, severe HI) were initially compared on injury and demographic characteristics and on a preinjury measure (VABS) to identify any differences across the groups that could influence postinjury performance. One-way analysis of variance (ANOVA) was conducted to compare standardized summary scores on cognitive measures across groups during the acute stage. Tukey's (HSD) statistic was utilised to ascertain specific group differences. Repeated measures analysis of covariance (Group $\times$ Time) was conducted to examine the association between injury severity and test performance at acute assessment and 6 months postinjury on tests of attention, with age at injury included as a covariate. Repeated measures two-way analysis of variance (Group $\times$ Time $\times$ Stage) was employed to investigate the association between test performance and injury severity on the sustained attention task, where performance in the first 5 min and last 5 min of the task was analyzed. For some measures, score distributions were unacceptably skewed due to extreme results. In such instances the child was assigned a score of 2 standard deviations below the mean for their group for the variable concerned.

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RESULTS

Comparison of Preinjury and Postinjury Abilities

To examine possible preinjury group differences for level of ability, the VABS results were examined (Table 3). Analysis indicated no group differences with respect to preinjury abilities on the VABS ($F < 1$). Comparison of preinjury and postinjury VABS revealed a significant main effect of time [$F(2,31) = .001$, $p < .01$], with all groups performing more poorly over time. While Group effects did not reach statistical significance, the pattern of deterioration of scores was consistent with injury severity, with the mild and moderate HI groups continuing to score within the Average range, and the severe HI group performing in the Low Average range.

Intellectual Performances

Table 3 provides results for the intellectual measures undertaken during the acute stage. Analysis of variance identified a significant group difference for VIQ [$F(2,39) = 3.63$, $p < .05$] and FSIQ [$F(2,39) = 4.46$, $p < .05$]. *Post-hoc* analysis indicated significant discrepancies for VIQ and FSIQ between the mild and severe HI groups. The mild HI group performed according to normative expectations, while the mean of the severe HI group was 1 standard deviation below the test mean. This same trend was evident for PIQ [$F(2,39) = 2.72$, $p = .07$], but did not reach statistical significance.

Attentional Skills

Sustained attention

Repeated Measures ANCOVA (Group × Time, covarying for age at injury) was conducted for attentional measures. Results on the CPT related to the severity of injury as seen in Table 4. With regard to the mean number of correct responses, main effects of group [$F(2,37) = 4.13$, $p < .05$] and time [$F(2,37) = 6.66$, $p < .05$] were identified, with the severe HI group achieving fewer correct responses than the other groups, at both acute and 6 months postinjury. All groups improved on this measure over time, suggesting some recovery of these skills in the first 6 months postinjury, or a possible combination of both recovery and familiarization with the task.

No main effect of group or time was evident for the total number of omission, commission, or impulsive responses. There was a trend for the severe HI group to make more omission and commission errors in comparison to the mild and moderate HI groups. With regard to the total number of missed responses, main effect of group [$F(2,37) = 3.52$, $p < .05$] was detected, with the severe HI group recording more missed responses at both acute and 6 month stages.

Mean reaction time scores from the CPT showed no evidence of significant group differences or recovery over time, as illustrated in Table 4. There was no significant main effect of group or time (Fs < 1). Of interest, the severe HI group exhibited a trend to shorter reaction times, possibly reflecting impulsivity, leading to a higher error rate.

The CPT was also analyzed in terms of Group × Time × Block (see Figures 1–6) to examine possible reductions in performance over time, relating to components of sustained attention. With regard to the mean number of correct responses, the main effects of group [$F(2,35) = 4.4$, $p < .05$], time [$F(2,35) = 8.9$, $p < .05$], and an interaction of Group × Block [$F(2,35) = 3.9$, $p < .05$] were each significant. The severe HI group achieved fewer correct responses in comparison to the mild and moderate HI groups; however, all the groups showed improvement over time. The severe HI group also showed the largest discrepancy in performance between the first 5 min and the last 5 min of the CPT, with significantly fewer correct responses made at the end of the task, in comparison to the mild and moderate HI group. This finding suggests a greater difficulty with sustained attention for the severe HI group both at acute and 6 month evaluations.

As in the *total* scores discussed earlier, mean reaction time scores for the CPT showed no significant main effects of group [$F(2,36) = 1.3$, $p = .29$], time [$F(2,36) = 2.1$, $p = .14$], or block ($F(2,36) = 3.0$, $p = .06$]. There was a trend for mild and moderate HI groups to respond slower at the end of the task, and the severe head injured HI group re-

Table 3. Results from pre- and postinjury VABS and acute intellectual evaluation

	Mild HI ($N = 13$)		Moderate HI ($N = 19$)		Severe HI ($N = 11$)	
Test score	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
VABS Total: Preinjury	110.0	(15.4)	107.6	(16.9)	104.5	(8.9)
VABS Total: Postinjury	108.8	(13.2)	99.4	(19.8)	88.8	(16.3)
Verbal IQ*,†	99.8	(15.4)	91.9	(14.9)	84.0	(14.9)
Performance IQ	103.4	(9.9)	97.3	(13.4)	89.5	(19.4)
Full Scale IQ**,†	101.5	(7.8)	93.9	(13.3)	85.5	(16.1)

*$p < .05$, **$p < .01$.
†*Post-hoc* analysis shows significant differences between mild and severe HI groups.

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Table 4. Results for attentional measures at acute assessment and 6 months postinjury

	Mild HI ($N = 13$)				Moderate HI ($N = 19$)				Severe HI ($N = 11$)			
	Acute		6 months		Acute		6 months		Acute		6 months	
Measure	Adj. *M*	(*SE*)	Adj. *M*	(*SE*)	Adj. *M*	(*SE*)	Adj. *M*	(*SE*)	Adj. *M*	(*SE*)	Adj. *M*	(*SE*)
Sustained attention												
CPT: Number correct*,**,[ab]	524.6	(28.1)	543.4	(24.4)	479.1	(25.7)	521.9	(22.3)	416.9	32.4)	437.9	(28.2)
CPT: Mean reaction time (ms)	599.5	(37.1)	621.1	(38.4)	648.1	(32.5)	629.1	(33.6)	589.7	(40.4)	583.8	(41.8)
Selective attention												
LCT: Number correct	36.5	(1.7)	40.1	(2.0)	34.5	(1.6)	36.7	(1.8)	31.5	(2.1)	32.1	(2.4)
Trails A: Completion time**,†,[acd]	17.2	(2.4)	16.8	(2.0)	22.1	(2.3)	18.6	(1.9)	31.3	(2.8)	22.0	(2.3)
Shifting attention												
Trails B: Completion time**,[b]	42.4	(5.5)	37.8	(5.8)	61.5	(5.2)	41.8	(5.5)	61.6	(6.3)	54.1	(6.7)
CNT: T4: Completion time	85.4	(8.7)	72.7	(7.6)	90.3	(7.9)	74.5	(7.0)	112.1	(10.0)	82.6	(8.8)

**Main effect of group, $p < .05$. *Main effect of time, $p < .05$. †Group × Time interaction, $p < .05$.
[a]Significant difference between mild and severe HI groups at T1; [b]significant difference between mild and severe HI groups at T2; [c]significant difference between mild and moderate HI groups at T2; [d]significant difference between moderate and severe HI groups at T1.

sponded more quickly toward the end of the task, although judging by the increased errors recorded by the severe HI group, these quicker reaction times do not necessarily reflect more efficient performance.

No significant main effects were detected for group, time, or block for omission and commission errors, although there was a trend of the severe HI group to make fewer omission and commission errors in the later stages of the CPT, as illustrated by Figures 3 and 4. For missed responses (Figure 5), a different pattern emerged. There was a significant main effect of block [$F(2,36) = 10.1$, $p < .05$] and a significant Group × Block interaction [$F(2,36) = 4.1$, $p < .05$]. All groups missed more responses at the end of the task, with the severe HI group achieving, by far, the highest number of missed responses in the last stage, with no evidence of improvement on this measure for acute to 6-month assessments. The trend toward fewer omission and commission errors toward the end of the task for the severe HI group may reflect the large number of missed responses at that stage of the CPT.

As shown in Figure 6, for the number of impulsive errors (reaction time 0–200 ms from the target being seen on the screen), significant interaction effects showed that the severe HI group made more errors at acute evaluation, with little evidence of recovery in performance. In contrast mild and moderate HI groups displayed improvement in performance on this variable for acute to 6-month assessment. In addition, severe HI group made fewer impulsive errors at the end of the CPT, while the other two groups either remained constant or increased their impulsive responses.

Selective attention

For the LCT, there were no significant main effects [group: $F(2,36) = 3.02$, $p = .06$; time: $F < 1$; and no interaction effect: $F < 1$]. However, a trend did emerge, indicating a

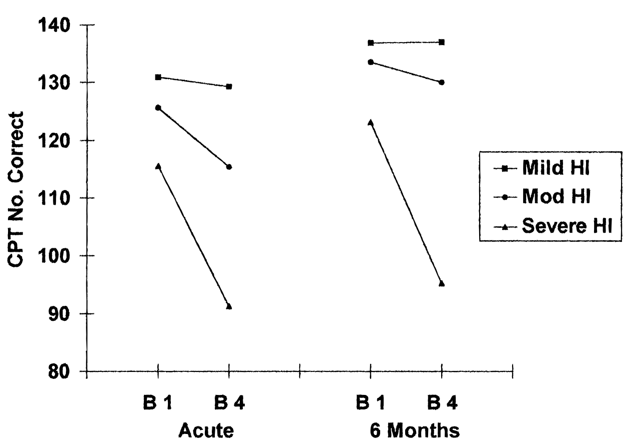

Fig. 1. Number correct on the CPT at the acute and 6-month stages postinjury. Number correct was calculated during the first and the last 5 min of the CPT at each time point.

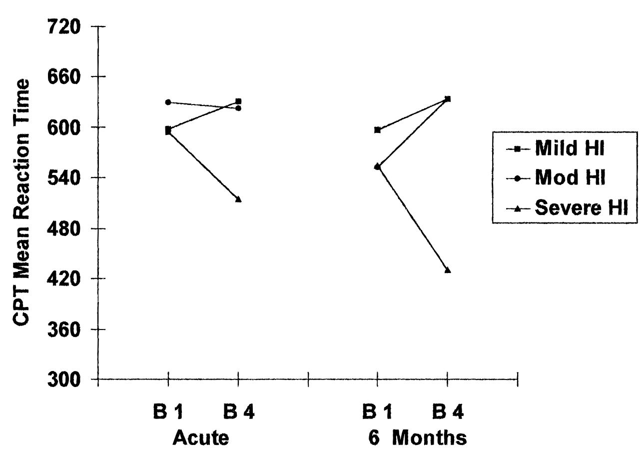

Fig. 2. Mean reaction time on the CPT at the acute and 6-month stages postinjury. Mean reaction time was calculated during the first and the last 5 min of the CPT at each time point.

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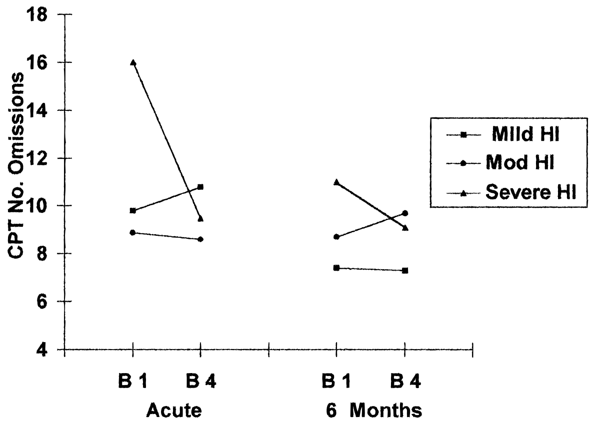

Fig. 3. Number of omissions on the CPT at the acute and 6-month stages postinjury. Number of omissions were calculated during the first and the last 5 min of the CPT at each time point.

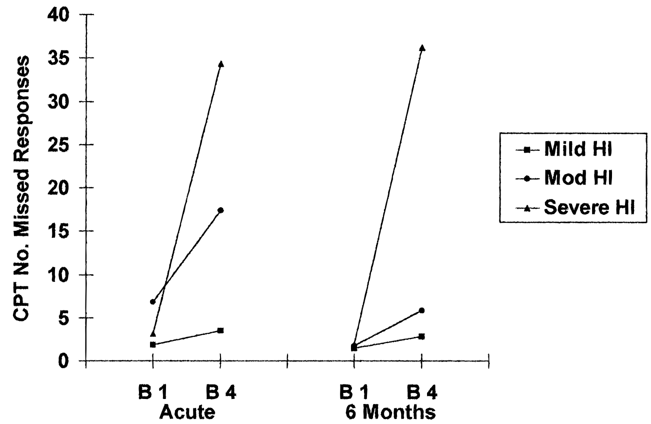

Fig. 5. Number of missed responses on the CPT at the acute and 6-month stages postinjury. Number of missed responses were calculated during the first and the last 5 min of the CPT at each time point.

tendency for the mild HI group to perform better during the acute and 6-month stages and for all groups to improve over time, with the severe HI group showing least improvement. These results are illustrated in Table 4.

For Trails A a significant effect of group [$F(2,36) = 4.95$, $p < .05$] and a significant Group × Time interaction [$F(2,36) = 5.01$, $p < .05$] was detected, with the severe HI group taking longer to complete the task, but also showing greatest gain (recovery) over time. The mild HI group did not record any such gains, supporting an interpretation that improvement associated with severe HI are due to recovery rather than a practice effect. See Table 4.

Shifting attention

Table 4 demonstrates the results for Trails B. Statistical analysis detected a significant main effect for group on this measure [$F(2,36) = 3.44$, $p < .05$], but no significant main effect for time ($F < 1$), and no interaction effect [$F(2,36) = 1.57$, $p = .22$]. *Post-hoc* analysis indicated that the mild HI group performed significantly better than either moderate or severe HI groups on this measure at acute assessment. However, at 6 months postinjury the moderate HI group performed similarly to the mild HI group, suggesting greater recovery in this group in contrast to relatively consistent performance of the other two HI groups. These results may reflect the added complexity of Trails B, indicating ongoing difficulties in higher level skills following more severe injury.

There was no significant main effect of group [$F(2,37) = 1.84$, $p = .17$], time ($F < 1$), nor an interaction effect ($F < 1$) on the CNT (Condition 4), although all groups exhibited a trend to quicker completion times at 6-month evaluation. These results are illustrated in Table 4.

DISCUSSION

The results of the present study provide support for the presence of attentional difficulties both acutely and 6 months

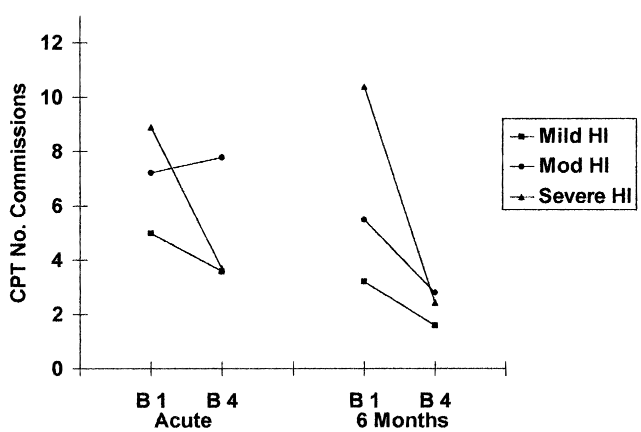

Fig. 4. Number of commissions on the CPT at the acute and 6-month stages postinjury. Number of commissions were calculated during the first and the last 5 min of the CPT at each time point.

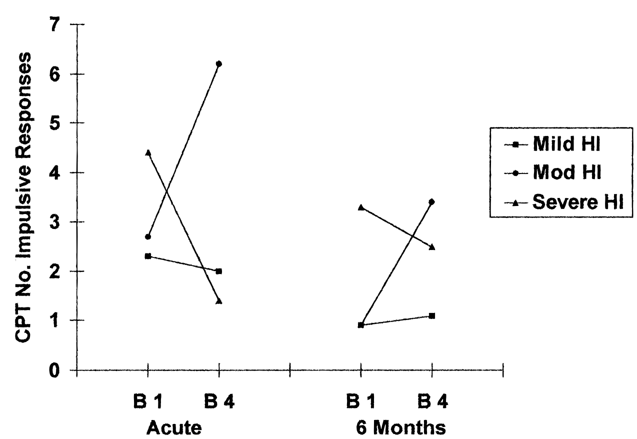

Fig. 6. Number of impulsive responses on the CPT at the acute and 6-month stages postinjury. Number of impulsive responses were calculated during the first and the last 5 min of the CPT at each time point.

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postinjury following head injury sustained during childhood. These deficits appear to be associated with injury severity, and cannot be explained in terms of preinjury abilities or demographic factors. As seen by the Vineland Adaptive Behavior Scale and demographic and socioeconomic status factors, all groups were functioning similarly prior to HI, so that any postinjury differences are likely to be attributed to injury-related factors rather than premorbid status.

Acute Measures

During the acute postinjury stage there was a significant difference between the groups on Verbal IQ and Full-Scale IQ, with a similar trend for Performance IQ. While the mild and moderate HI groups performed within the Average range on these measures, the severe HI group performed outside of this range, with scores significantly below those of the other HI groups. These results support the generally reported dose–response relationship between injury severity and IQ. However, they are inconsistent with previous research in both adult and child populations, which has documented greatest impact on Performance IQ. While the difference in performance between mild and severe HI groups is similar for both VIQ and PIQ, the severe HI group exhibited a large standard deviation for PIQ, possibly leading to the nonsignificant difference observed among the groups.

Attentional Measures

Results on the attentional and information processing tasks also indicated a dose–response relationship, which appeared to persist during the acute and subacute phases postinjury. Interestingly, both level of competence and recovery patterns varied depending on the specific attentional component being measured. It may be postulated that this variability in recovery may depend on the specific cerebral regions impacted by injury, and their level of maturity.

Sustained attention

The severe HI group achieved fewer total correct responses at both acute and 6-month stages. However, all groups improved over time, suggesting some recovery of this skill as generalized effects of HI diminish. In fact, the moderate HI group showed most improvement and the mild HI group the least improvement, demonstrating that the improvement seen is likely to be due to recovery rather than familiarization with the task.

Contrary to expectations from adult literature, there were no statistically significant differences between groups for speed of response, thus failing to support an argument that slowed response rate underpins attentional deficits post-HI in children. Similarly, no group differences were detected for omission, commission, or impulsive errors. There was a trend for the severe HI group to do more poorly in these areas, but the small sample size gives the study limited power to detect these differences. When analyzing differences between the first and last 5 min of the task, the severe HI group again achieved fewer correct responses toward the end of the task, at both acute and 6-month stages, getting progressively poorer as the task progressed, indicating that severe HI is associated with greatest deficits in sustained attention. Similarly, the severe HI group missed responses more frequently toward the end of the task, showing little improvement over time in comparison to the moderate HI group. Such findings are consistent with those of Kaufman et al. (1993) and Timmermans and Christensen (1991), where children with a head injury demonstrated significant difficulties sustaining attention.

Selective attention

As for measures of sustained attention, findings suggest that injury severity is related to outcome in this area of attention. Results on Trails A support the possibility of visual selective attention and information processing deficits as the severe HI group took longest to complete this task at both acute and 6-month stages. However, the severe HI group showed substantial improvement over time. Results on the LCT were in the expected direction, even though there were no significant differences between the groups. That is, the mild head injured group achieved highest number correct in 1 min and the severe group achieved fewest number correct. Of importance, this measure is dependent on visuomotor speed and co-ordination, so it may be interpreted that the severe group has poorer selective attention, slowed visuomotor processing, or a combination of these. Such results do provide partial support for findings in the adult literature, where reduced speed of information processing has been implicated as a confounder on tasks measuring attentional skills (Anderson & Pentland, in press; Ponsford and Kinsella, 1992; Stuss et al., 1989). However, our results suggest that these problems are specific to visuomotor performance with simple processing speed (i.e., reaction time) intact. Furthermore, the LCT task is a more visually overwhelming task in comparison to Trails A, suggesting that the severe HI group improve on simple tasks (Trails A) but still struggle on tasks of higher demand.

Shifting attention

Children with a moderate or severe HI demonstrated a reduced ability to shift attentive focus effectively on the Trails B task. The moderate and severe HI groups completed tasks requiring a shift in attention more slowly during the acute period, with the moderate group showing much improvement over time and the severe group showing least improvement over time. Again, it is difficult to determine whether the severe group has difficulty shifting attention or that the difficulty is more complex; that is, poor ability to divide attention in conjunction with slowed visuomotor processing exacerbating differences on this task. Such an interpretation is consistent with Wood's argument that head injury may limit attentional capacity by reducing the extent to which attention can be divided across stimuli, thus affecting the

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ability to shift between modes of thinking, and resulting in slower and even less reliable processing of information (Wood, 1988). No significant differences were detected on the CNT although the severe HI group showed substantial improvement over time. However, this task was not commenced until children had mastered the rule by participating in practice trials. This repeated exposure may have improved the severe HI group's ability to perform the task with more confidence, accuracy, and speed.

To summarize, moderate and severe head injury during childhood results in specific attention and information processing deficits in the acute postinjury phase. Not all areas of attention are affected similarly, with factors including the nature of the task (e.g., visuomotor tasks in comparison to computerized reaction time tasks), task complexity, and speed requirements affecting acute and 6-month outcome. These results provide partial support for findings from the adult literature where deficits for speed of processing are reported (Murray et al., 1992; Ponsford & Kinsella, 1992). However, while adult head injury is thought to be a general disruption to attention and information processing (Van Zomeren & Brouwer, 1994), this current study revealed that deficits seen in severe HI children are not generalized, with simple motor speed relatively intact, but visuomotor processing more impaired. In addition to these deficits identified in adults, evidence for impairments in sustained attention was also found, with these deficits most evident in severe HI. With respect to selective and shift measures, dose-related deficits were identified; however, it is difficult to separate attentional effects from visuomotor processing requirements. Future research may be directed towards more accurate delineation of these skills. The more widespread attentional difficulties seen in childhood HI may reflect the relatively immature state of the central nervous system at the time of injury. Thus attentional skills not developed (e.g., sustained, shift, and processing speed) will be more vulnerable and less likely to develop normally, and so cumulative deficits may also result after HI in childhood (McKay et al., 1994).

Conclusions

In conclusion, the present study suggests that attentional deficits do occur and persist following a closed head injury, with degree of impairment related to injury severity. Children sustaining a severe HI performed more slowly on a range of tasks that were timed and required visuomotor skills. These children also demonstrated difficulty in the area of sustained attention. It is important to note that children with mild HI performed relatively well on all attentional measures, suggesting minimal impact of injury for these children. Inconsistent results on measures of selective and shifting attention reflect the difficulties in making accurate interpretations on these multiply determined measures. It is important to look closely at measures of attention in order to ascertain whether these tasks are purely measuring what they pertain to measure, or whether each task is in fact measuring a number of skills some of which recover more quickly than others following a closed head injury. It has been argued that deficits in attention and speed of processing may impede future learning and acquisition of knowledge, resulting in current and cumulative deficits, and so it is important to gain a better understanding between the general term of "attention deficits" and developmental factors.

These data represent the first stage in a longitudinal study, in which the children will be followed to 24 months postinjury. This will allow recovery profiles to become clearer and will also assist in determining which skills are most important in determining a favorable outcome on attentional measures. Such an investigation of attentional recovery over time, as was commenced in this paper, will lead to a better understanding of long-term outcome following pediatric head injury, leading to more relevant rehabilitation programs in the behavioral and educational areas.

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