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Cognitive Effects of Mild Head Injury in Children and Adolescents

Sue R. Beers[1]

A comprehensive review of recent neuropsychological studies of mild head injury (MHI) involving children and adolescents is presented. The seminal work of Rutter and his colleagues is reviewed. An alternative conceptualization of MHI as proposed by various researchers is elaborated and further research investigating the cognitive sequelae of MHI is reviewed. MHI is discussed within the context of development and information processing models. Finally, the sequelae of MHI are reviewed with respect to academic functioning. Methodological problems inherent in studies of MHI are identified and discussed. The studies reviewed here support the conclusion that both the cognitive and emotional consequences of MHI should receive serious evaluation.

KEY WORDS: neuropsychological assessment; mild head injury; development; information processing.

INTRODUCTION

Each year approximately 3 million persons in the United States sustain a closed head injury; between 140,000 to 280,000 of these individuals manifest residual physical, intellectual, or behavioral deficits (Bigler, 1987a, 1987b). The actual incidence of head injury may be much higher, however, because an estimated 20–40% of individuals who sustain mild head injury (MHI) seek no medical attention (Alves and Jane, 1985; Jennett, 1989). Despite this limitation, demographic studies have established that the frequency of head injury increases in the under-24 age group, with males ages 15–24 two times more likely to sustain head injury than females (Bigler,

[1]VA Medical Center and Western Psychiatric Institute and Clinic, Pittsburgh, Pennsylvania.

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1987a, 1987b). In fact, several researchers report that about 62% of all new cases of head injury occur in individuals under age 24 (Kalsbeck *et al.*, 1980; Klauber *et al.*, 1986). It is clear, then, that traumatic head injury is a major contributor to sequelae associated with neurologically based disease in children and adolescents (Fletcher and Levin, 1988).

Yet despite these statistics that reveal head injury to be a significant health problem in the United States, MHI is termed by some as the "silent epidemic" (Gouvier, 1986). This appellation was bestowed not only because many persons sustaining head injury are never admitted to a hospital (Colohan *et al.*, 1986), but also because their symptoms—symptoms that can occur weeks or months after the injury—are often attributed to other causes (Alves *et al.*, 1986; Barth, 1989; Barth *et al.*, 1986; Boll and Barth, 1983; Jennett, 1978; Lidvall *et al.*, 1974).

The head-injury literature distinguishes between concussion and moderate to severe head injury (Binder and Rattok, 1989). Generally, MHI, or cerebral concussion, is indicated if patients manifest no known structural brain lesions. A concussion occurs with a disruption of neurological function caused by a direct blow to the head or a rapid acceleration and deceleration (e.g., violent shaking, whiplash). Loss of consciousness is not always present.

For the past century controversy has surrounded the question of whether organic—as opposed to psychogenic factors—are the primary determinants of "Postconcussion Syndrome," often equated in the literature with the sequelae of MHI (Benton, 1989; Rosenthal and Berrol, 1986). Individuals, either adults or children, who function normally on a neurological examination after MHI but who complain of headaches, increased anxiety, emotional lability, concentration problems, and memory lapses are frequently viewed as suffering from Postconcussion Syndrome, or in other words, from a psychological disturbance (Miller, 1961).

MHI per se was not studied in detail until the 1980s when an increased recognition of the public health implications of less severe injury spurred researchers to develop better understanding of this portion of the injury spectrum (Barth, 1986; Conboy *et al.*, 1986; Eames, 1986; Marshall and Marshall, 1985). The majority of this research in the 1980s, however, involved the adult population and has been extensively reviewed elsewhere (cf. Levin *et al.*, 1989).

With recent improvements in technology, physiological (Jane *et al.*, 1982; Rutherford, 1989; Salazar, 1992; Schoenhuber and Gentilini, 1989; Thatcher *et al.*, 1989) and histological (Gennarelli, 1986, 1987; Margulies and Thibault, 1989; Povlishock *et al.*, 1983) studies are beginning to identify specific *neuropathologic* contributions to the postconcussion symptoms that accompany MHI. These findings support the contention espoused much earlier by Symonds (1962) who reviewed the literature of the previous 20 years:

> As a result of concussion of any degree there may be a permanent loss of neuronal function . . . it is questionable whether the effects of concussion, however slight, are ever completely reversible. (p. 4)

This paper presents a comprehensive review of the more recent neuropsychological studies of MHI involving children and adolescents as well as a brief overview of the methodological issues inherent in the attempt to establish cause of deficits seen after such injury. Finally, conclusions and recommendations regarding the sequelae of MHI in children and adolescents are presented.

MILD HEAD INJURY

This section focuses on research investigating the aftermath of MHI occurring in childhood or adolescence, with emphasis on the distinctive problems developmental considerations add to an already complicated picture. It concentrates on the research completed since 1980, although relevant earlier work is included. First, the seminal study of Rutter and his colleagues is reviewed. This important work concerning both mild and severe head injury in children profoundly influenced the direction of subsequent research. For this reason, it is critiqued in detail. Second, an alternative conceptualization of MHI as proposed by various researchers is reviewed. Next, studies of MHI are discussed in terms of sequelae of injury, developmental considerations, and information processing. Finally, the sequelae of MHI are reviewed with respect to their impact on academic performance.

The Rutter Study

Rutter (1981) posits that the key to the controversy surrounding the effects of MHI is found in the study of change as well as in the study of cause. Generally, acute damage to the brain precipitates intellectual deficit that shows progressive improvement over successive months. This change, or pattern of recovery, provides strong indication that the initial deficits were a consequence of the acute damage. In the extensive, prospective study reviewed in detail below, Rutter and his colleagues (Brown *et al.*, 1981; Chadwick, Rutter, Brown *et al.*, 1981; Chadwick, Rutter, Shaffer, and Shrout, 1981; Rutter *et al.*, 1980) found that there was a phase of marked cognitive recovery in the group of children with severe head injuries; but no such recovery phase was observed in the mild injury group. They concluded, then, that the deficit established in the former children was due to the brain injury, but the deficit in the latter group was not.

Rutter suggests that the question of cause is addressed by an examination of the dose–response relationship; that is, the linear relationship between the severity of injury and the extent of intellectual deficits. Again, Rutter cites his prospective study as providing evidence that such a relationship exists for severe, but not for mild, head injury.

Rutter and his colleagues (Brown *et al.*, 1981; Chadwick, Rutter, Brown *et al.*, 1981; Chadwick, Rutter, Shaffer, and Shrout, 1981; Rutter *et al.*, 1980) conducted one of the first, largest, and most frequently cited prospective study of the full spectrum of head injury. As elaborated above, this study addressed the issues of change (i.e., the recovery curve) and cause (i.e., the dose–response relationship) with respect to the cognitive sequelae of traumatic brain injury in children.

Design

Two important theoretical considerations shaped the design of this study. The initial premise was that children who experience head injury are not a random sample of the population; cognitive and behavioral problems are frequently present that predate brain injury. The second theoretical premise was that of a threshold effect that operates with head injury. Rutter and his colleagues attempted to identify the threshold, or level of severity, above which cognitive impairment might arise as well as the patterns of cognitive deficit that might be specific to the brain injury.

Rutter *et al.* developed this prospective longitudinal study, then, to examine the premorbid functioning and identify a threshold of injury as well as to explore the extent, nature, and recovery course of any cognitive or behavioral impairment. The study sample was composed of three groups of children, ages 5–14 at the time of their accident. The severe head-injury group consisted of 28 children who experienced posttraumatic amnesia (PTA) of at least 7 days. These children were obtained from admissions at six Regional Neurosurgical Units serving southeast England. Children who suffered PTA of over 3 months and those who developed an extradural hematoma were excluded from the study.

A control group of 28 children, carefully matched with the severe head-injury group, was made up of children who had sustained orthopedic injuries. This control group was utilized to address several methodological considerations. First, this group provided a control for both the predisposing factors that may have put the child at risk for accident and the nonspecific consequences of head injury such as admission to a hospital or physical incapacity. Second, due to the longitudinal nature of the study, the control group was needed to distinguish test practice effects from true cognitive gains made during recovery. Third, the control group was used to calibrate the scores of nonstandardized tests used in the study. Finally, because cognitive impairment and behavioral problems arise for reasons other than head injury, the control group was included to determine which and how much of the cognitive impairments and behavioral sequelae were specifically due to brain injury.

In order to determine the threshold above which either transient or permanent sequelae might occur, Rutter *et al.* selected another comparison group of children with MHI. This sample of 29 children had sustained PTA of less than 7 days but more than 1 hour. Most of these children were obtained from the same local hospitals used to form the control sample. This mild injury group, however, was *not* matched to the severe injury group. This cohort included a higher proportion of boys, more children from disadvantaged backgrounds, and more children who evidenced school achievement and adjustment problems before the accident.

Rutter *et al.* used parental interviews, questionnaires, teacher interviews, cognitive tests, behavior ratings, and neurological examinations to evaluate the sample. Of note, however, is that fact that all the groups were not assessed at the same intervals or by the same instruments. Parental interviews, following the style developed earlier by the principal investigator (Graham and Rutter, 1968; Rutter and Brown, 1966), took place with the mother in the home as soon as possible after the accident, and again at 4 months, 1 year, and $2^1/_4$ years later. One parent, usually the mother, completed a written measure, the Conners' Paternal Questionnaire, before each interview. Teachers also completed a questionnaire, the Rutter B2 Scale, at the time of initial assessment and at the 1- and $1^1/_4$-year intervals. Teacher interviews, however, were done at the final follow-up for *only* the severe head-injury group.

Children with mild injury were given a more limited neuropsychological assessment than the rest of the sample. Cognitive testing for the mildly injured group included six subtests of the Wechsler Intelligence Scale for Children (WISC): Similarities, Vocabulary, Digit Span, Block Design, Object Assembly, and Coding. These tests were administered at various intervals depending on the level of injury and impairment noted. School performance as assessed by the Neale Analysis of Reading Ability, Arithmetic of the WISC, and a translation task devised to measure ability to work independently under distracting conditions for an extended period of time.

It is a serious weakness of this study that only the severe and orthopedic-control children were examined with a more extensive battery of neuropsychological tests shown to be sensitive to the effects of brain injury. These tests included the Paired Associate Learning Test, Continuous Performance Task, Stroop Color-Word Test, Matching Figures Test, Object Naming Test, Verbal Fluency Test, and measures of manual dexterity and a quantified assessment of repetitive finger movement.

Hynd (1988, 1990) cautions against using global measures such as the WISC to make subtle neuropsychological discriminations. Because children with MHI are more apt to have generalized brain damage rather than focal lesions, assessment instruments that detect deficits related to diffuse injury and subtle brain dysfunction are appropriate for this group. Rutter *et al.*'s use of global measures to assess the elusive deficits usually associated with MHI and the more fine-grained neuropsychological measures to uncover the more obvious deficits usually associated with more severe injury is a serious flaw in the assessment procedure.

Intellectual Functioning

Examination of the WISC Verbal-Performance IQ discrepancies revealed that in both the control and MHI group the observed differences were small and not statistically significant. In the more severe injury group, however, almost a third of the children showed Performance IQ greater than Verbal IQ by at least 25 points. This discrepancy, however, did not persist 1 year after injury. The authors suggest that these Verbal-Performance IQ discrepancies are not much more common in severely injured children than in the general population. In view of other findings regarding the impairments of the severely injured group found in this study, an alternative conclusion is suggested. Six subtests of a global measure of intellectual functioning such as the WISC might not be sufficient to delineate deficits associated with head injury.

Course and Pattern of Recovery

The authors found no recovery phase after MHI and proposed that the observed cognitive limitations in the MHI children predated injury; that is, their injury did not cause the deficits. In the severe injury group, Rutter *et al.* concluded that the dose–response relationship found between severity of injury and the degree of intellectual impairment confirmed that the intellectual deficits were caused by the head injury. The authors based these conclusions regarding cognitive function of the mild and severe groups, however, on statistical comparisons of only three Verbal and Performance subtests of the WISC, the results of parental questionnaires, and a review of the accident situations.

The evaluation of school performances of the children revealed that although the mild injury group exhibited a high rate of reading backwardness, there was no suggestion of a recovery pattern over the $2^1/_4$ years. In contrast, improvement by the most severely injured children continued through the study interval. Analysis of the results from measures of scholastic impairment suggested that persistent impairment occurred only after very severe injury.

Although the authors point out that the brain injury in the mild group might be different in type and that the nature of the brain pathology might not allow for recovery, they fail to address the issue of the *pattern of recovery*. Several investigators (Alves *et al.*, 1986; Conboy *et al.*, 1986; Marshall and Ruff, 1989; Povlishock *et al.*, 1979; Ruff *et al.*, 1986) suggest the possibility that the recovery curve seen in MHI is much more gradual than that observed in moderate to severe injury.

Threshold of Injury

The analyses of the test results across 3 subgroups of the severely injured children classified by length of PTA and their matched controls pointed to a broad threshold of impairment without a definitive cutoff point. Persistent intellectual impairment rarely occurred in the subgroup with the least injury (PTA of 1–2 weeks).

Because the mildly injured children had no matched control group, that sample was divided into two injury level categories (PTA < 24 hours; PTA > 24 hours) and the Verbal and Performance IQ scores, extrapolated from the six subtests of the WISC, were compared to assess the threshold of injury. This analysis of the mild injury group suggested minor transient intellectual deficits in the group with PTA over 24 hours. The authors point out that their conclusions rested on the results of a global measure of IQ, rather than a more specialized test that might better delineate cognitive impairments.

Premorbid Differences Between MHI and Severe Groups

An important issue in the study of MHI is whether children who sustain mild injuries are different from those who sustain more severe injury. These authors feel that the recovery curve as well as circumstances of injury lend support to the hypothesis that children who incur MHI do have premorbid differences. Rutter *et al.* explain the higher number of psychiatric problems, lower level of scholastic attainment, and lower IQ levels of the mildly injured group when compared to controls by referring to the pattern of risk found in large epidemiological studies of head injury. It is of note, however, that the MHI group was not matched to the other study groups in terms of SES.

Although the conclusion that children or adults sustaining MHI are those who manifest premorbid characteristics such as maladjustment or risk taking is often cited in the literature (Haas *et al.*, 1987; McLean *et al.*, 1983), there is some evidence to refute this claim. Miller (1986) believes that the relationship between preinjury "maladjustment" and posttraumatic outcome has not been clearly established. He suggests that the controls (hospital workers or college students) used in many studies inflate premorbid differences between noninjured and MHI groups. In a study of primarily mild head-injured adults, he found posttraumatic adjustment problems were not confined to patients with either premorbid personality or adjustment problems (Bornstein *et al.*, 1989). The data suggested the importance of using information regarding neuropsychological deficits to help understand the posttraumatic emotional and personality disturbance.

Rutter *et al.*'s conclusion of poorer premorbid functioning of the MHI group is also weakened by the fact that the assessment of preinjury problems was done via structured parental interviews at a time of crisis. Rutter provided reliability and validity information on this assessment technique. It is of note, however, that in these studies of the psychometric properties of the parent interviews (Rutter and Brown, 1966) the mothers interviewed did *not* have children in acute crisis and they knew that they were part of a research study. This interview method, therefore, may not provide a valid assessment of premorbid function because "family members . . . may or may not be accurate as such reports could be influenced by multiple factors including distress level of the reporter" (Dikmen, 1989, p. 103). In the present study, the level of injury could have affected the report of the parent. Fletcher *et al.* noted discrepancies in the results of parent interview vs. parent checklist in their study of behavioral changes in children after head injury (Fletcher *et al.*, 1990). They suggested that the determination of behavioral change in children depends on what aspects of behavior are assessed and how the assessment is completed.

In an apparently subjective comparison of the circumstances of injury of the three study groups, Rutter and his colleagues concluded that many of the mild head injuries resulted from reckless behavior in poorly supervised situations. They suggested that this recklessness supported the presence of vulnerability (e.g., lower IQ, impulsivity, increased behavior problems) often observed in children who incur a MHI.

Inspection of the data, however, reveals that the circumstances of the accidents of the orthopedic controls are not dramatically different from the circumstances of the mild head-injured children. This is especially true if the direct assault category is disregarded for the mild injured group. The direct assault circumstance is perhaps a reflection of the lower SES of the MHI group rather than the behavioral or intellectual characteristics of the children. Moreover, the data suggest that severity of injury depended not upon IQ or behavior differences, but upon whether or not an automobile was involved.

Summary

Rutter and his colleagues found that there was a marked cognitive recovery phase in the group of children with severe head injuries but no such recovery phase in the mild injury group. This change, then, implied that the deficits in the severe injury group were due to the brain injury. The lack of change in the MHI group indicated the deficits were not due to the head injury, but to the poorer premorbid functioning attributed to those who incur MHI. The authors concluded that the establishment of the strong dose–response relationship between injury severity and the presence of intellectual impairment confirmed that the cause of the impairment was the head injury. In addition, this relationship existed only above a certain threshold; that is, it was present in severe but not in MHI. Therefore, Rutter *et al.* concluded that the deficits associated with mild injury could not be caused by the head injury.

Postconcussion Syndrome: An Alternative Conceptualization

As the research of the 1980s began to provide a better understanding of the full spectrum of head injury, children and adolescents with MHI were found to exhibit personality changes, headaches, irritability, school learning difficulties, and memory and attention deficits (Boll, 1983). Casey *et al.* (1986) suggested that these symptoms were due to Postconcussion Syndrome, and hypothesized the cause to be an overreaction to the injury by the parents. This classification of the sequelae of MHI, whether in adults or children, as Postconcussion Syndrome suggests qualitative differences between the symptoms produced by mild and severe head injury.

Other researchers, however, proposed an alternative to the conceptualization of Postconclusion Syndrome as a psychogenic disorder. Rimel *et al.* (1981, 1982) argue that the problems experienced by persons sustaining mild head injuries are not likely to be qualitatively different from those who suffer more severe injury. They suggest the quantitative difference seen reflects the degree of damage to the brain.

This broader view of Postconcussion Syndrome accommodates an understanding of psychological functioning based on the brain–behavior changes. In other words, when an individual's basic and higher level cognitive processes are affected, an increase in anxiety and depression becomes more probable. Armstrong (1987) supports this perspective. She suggests that individuals whose defense mechanisms are constricted prior to injury, allowing limited coping under relatively unchallenging conditions, or whose identities are defined by rigid ego dynamics may be particularly affected by the sequelae of MHI. Adams and Putnam (1991) agree, suggesting that personality variables should receive more attention in the study of traumatic brain injury.

Colohan *et al.* (1986), noting the significant number of mild head-injured individuals who have complaints even when neurological examination is normal, suggest that the complaints following this type of head injury are a result of both organic and psychologic interactions (cf. Alves and Jane, 1985; Dikmen *et al.,* 1989; Ewing-Cobbs *et al.,* 1985; Lidvall, 1975; Rutherford, 1989). Kay (1986), however, elaborates that treatment considerations render the organic vs. functional distinction important. Secondary psychological reactions may be amenable to more traditional psychotherapeutic treatment, but organically based problems are not.

Like Rutter and his colleagues (Chadwick *et al.,* 1981). Alves *et al.,* (1986; Barth *et al.,* 1983; Rimen *et al.,* 1981) conclude that MHI manifests itself through no single symptom complex or syndrome. This view is also supported by the earlier research of Rutherford *et al.* (1977, 1979) and Lidvall *et al.* (1974). Unlike Rutter, however, these authors stress that MHI is not likely to be qualitatively different from more severe injury, but rather reflect the severity of cranial pathology (cf. Barth, 1986; Gennarelli, 1986; Rimel *et al.,* 1981, 1982). Summarizing the work needed in this area, Alves states that a complete explanation of posttraumatic symptoms of MHI must include an understanding of the patterns of impairment observed in individuals who have symptoms immediately after the injury as well as, and perhaps most importantly, those who report no symptoms.

Boll, Barth, and colleagues propose that mild head trauma in adults can result in temporary or even permanent neurological disruption, and in cognitive, behavioral, and emotional deficits (Alves *et al.,* 1986; Barth *et al.,* 1983; Rimel *et al.,* 1981). In general, results of their large study conducted at the University of Virginia Medical Center showed that MHI individuals sustained organic brain damage that caused problems in attention, concentration, memory, and judgment. A significant percentage of these mildly injured individuals, even those with average or above average IQ, demonstrated cognitive impairment after injury.

Although studies of adults with MHI within the established work force abound, little research has extended investigation to the population of younger adults still involved in academic pursuits. Barth *et al.* (1989; Barth, 1990) conducted a 10-university prospective study that evaluated 2350 football players from the Ivy League and the Universities of Pittsburgh and Virginia who had sustained extremely mild head injuries. Approximately 42% of the research group reported a history of at least one minor head injury, 11% reported at least two such injuries, and 11.6% had sustained three minor head injuries. Players and student controls were evaluated for cognitive and psychosocial dysfunction. Neuropsychological tests and self-report questionnaires were administered at four intervals.

The results of this four-year study are perhaps even more significant because the injuries were so benign. Mild injury was operationally defined as the *alteration* or loss of consciousness of less than 2 minutes, and the immediate demonstration of attention and/or memory problems. Neuropsychological testing included the Trail Making Test-A and B, the Symbol Digit Test, and the Paced Auditory Serial Addition Task (PASAT). Players and controls were tested at preseason, 24 hours postinjury, 5 and 10 days later, and at the end of the football season.

Analyses of test data revealed the following results. Head-injured players maintained their preseason baseline PASAT scores on the 24-hour postinjury testing, then began to display recovery in the 24-hour to 5-day interval. This statistically significant improvement continued through the 5–10-day interval and leveled off by the postseason testing. This pattern contrasts with that evidenced by the control students who experienced the expected practice effects. Student controls showed statistically significant improvement from the baseline testing to the 24-hour interval and also between the 24-hour and 5-day interval. At the 5–10-day and 10-day to postseason interval, however, the controls showed no statistically significant difference in their scores. This same pattern of recovery occurred for each group on the Digit Symbol Test but not on either section of the Trail Making Test. The authors report data analysis continues with respect to the effect of previous head injury or injuries for this sample.

These results suggest that an extremely mild head injury produced cognitive and/or information processing deficits manifested as failure to benefit from practice effects that can be demonstrated through neuropsychological assessment within 24 hours of injury. Rapid recovery appeared to take place over the next 5–10 days. These findings are similar to those of Levin *et al.* (1987) and McLean *et al.* (1984), who reported rapid recovery of function after MHI in a similar population of nonpremorbidly impaired adults. Based on their work with adults as well as younger persons having extremely mild head injury, Alves and his colleagues believe the work of the past 10 years indicates the genuineness of symptoms seen in many persons sustaining MHI. It is this research involving children and adolescents that will be reviewed in subsequent sections

Mild Head Injury in Children and Adolescents

This section includes studies of MHI in children and adolescents. Research is reviewed that investigates the cognitive sequelae of such injury. Measures of injury severity and the problems that surround their use with children are discussed; studies that explore the course of recovery are reviewed. Finally, the results of these studies are discussed within a developmental context.

Cognitive Sequelae

In an early descriptive study of what they term Posttraumatic Syndrome in children, Black *et al.* (1969) provided a prospective analysis of a series of unselected consecutive case of head injury. This study reported the results of a 2-year evaluation of 105 children injured between the ages of birth to 14 years. No control group or inferential statistics were used. Although the emphasis was on the comparison of posttraumatic complaints and behavioral sequelae with pretraumatic status, it is not clear how the level of premorbid functioning was established. Head injury ranged from mild to severe, but most individuals received a rather mild injury—37% sustained injury with no loss of consciousness and 18% endured a coma of less than 1 minute.

The analysis of the occurrence of major symptoms of Posttraumatic Syndrome (designated as headache, anger control problems, hyperkinesis, and impaired attention) at 1 year after injury was complicated by the fact that about one-third of the sample demonstrated premorbid occurrence of at least one of the major symptoms. The sample, therefore, was divided into two groups based on premorbid functioning, "normal" or "problems before injury." One year after injury, 31% of the *normal* group exhibited either headache (9%) or behavioral disturbance (22%). Only first-year data are included; the authors, however, report the second-year follow-up findings to be quite similar. Although the authors concluded that about 80% of their sample was unaffected by head injury occurring 2 years earlier, it is difficult to support these conclusions due to the fact that no control group or inferential statistics were included in the study.

In contrast, the following study presents some of the strongest evidence to support the study of the effects of head injury in school-aged children. In this carefully designed study, Gulbrandsen (1984) tested 56 children, 9–14 years of age, 4–8 months after receiving a "light" head injury. About 60% of the children either did not lose consciousness or were unconscious for less than 5 minutes. In response to the studies by Rutter that suggested the deficits seen in mild head-injured youngsters were linked to premorbid characteristics, Gulbrandsen developed both stringent exclusion criteria and control groups carefully matched for sex, age, school grade, and academic achievement. The children were tested with measures from the Reitan-Indiana Neuropsychological Test Battery for Children: Category Test, Tactual Performance Test, Trail Making Test, Finger-Tapping Test, Halstead-Wepman Screening Test for Aphasia, Seashore Rhythm Test, and the Stereognosis Test. The Grooved Pegboard Test and the Wechsler Intelligence Scale for Children were also included.

The performance level of the experimental group was below the control group on 29 of the 32 variables. Two-way analysis of variance was performed to test for significant differences across groups. The concussion factor exerted a main effect in seven of the comparisons. The differences between groups increased as a function of the complexity of the test measure. Three of the tests (Tactual Performance Test, Grooved Pegboard Test, and WISC Picture Arrangement) that differentiated the experimental from the control group were nonverbal and timed. Results from this detailed neuropsychological assessment indicated the presence of subtle but measurable decrements in cognitive functioning related to complex nonverbal tasks with time constraints.

This study, then, identified quantitative changes; that is, the mildly injured children showed patterns of impairment in the same areas found to be disrupted by more severe head injuries. This contrasts with the conclusions of Rutter *et al.* (Brown *et al.*, 1981; Chadwick, Rutter, Brown *et al.*, 1981; Chadwick, Rutter, Shaffer, and Shrout, 1981; Rutter *et al.*, 1980), who discussed the changes they identified in qualitative terms. In other words, as changes that did not follow the same pattern as those seen after moderate to severe injury.

In view of clinical experience suggesting that head-injured children exhibit slowed motor reactions, Bawden *et al.* (1985) designed a retrospective study to compare the performances of children having different severity of injury on speeded and nonspeeded measures of motor, visual-motor, and visual-spatial functioning. Subjects were grouped primarily by their level and duration of unconsciousness. Children with a Glasgow Coma Scale score of 7 or below at the time of injury were included in the severe group. Those with scores above 7 were assigned to the moderate or mild group, depending on the duration of unconsciousness and level of neurological indices. Children who had a history of previous psychiatric disorders were excluded from the study. Both mildly and moderately injured children were matched for gender, age at injury, and age at testing to the 17 severely injured children. There was no indication, however, of matching for SES variables. Unfortunately, a normal control group was not included in this study. Mean age of the entire sample was 10.5 years and mean injury–test interval was approximately 1 year. The Weschler Intelligence Scale for Children—Revised (WISC-R) and either the Knights-Norwood adaptation of the Halstead-Reitan Neuropsychological Test Battery for Children or the Reitan-Indiana Neurological Test Battery for young children were administered in a standardized manner. One-way analyses of variance and least significant difference multiple comparison tests were used to compare the performance of the head-injured groups on the 29 neuropsychological variables.

Relative to the other two groups, the severely head-injured children exhibited an impairment on the Performance IQ (PIQ) scale, but not on the Verbal IQ (VIQ) scale. This finding agrees with the results of Chadwick *et al.* (1981). The major conclusion of this study was that severely head-injured children performed significantly slower than mildly to moderately injured children on several tests of motor speed (Finger-Tapping, Foot-Tapping, Grooved Pegboard) and on a test requiring motor speed and visual-spatial skills, Coding. The performance of the mild and moderate injury groups was similar on these highly speeded tests. No conclusions can be drawn, however, regarding presence or absence of deficit in children with less severe injury because no normal control group was used.

These studies of the neuropsychological sequelae of MHI seen in children as well as adults began to call into question Rutter's hypothesis of a threshold effect above which occurs a linear relationship between various indices of severity and outcome. Boll and Barth (1983) suggest that outside the sphere of severe brain injury, defined as an obvious destruction of brain tissue and loss of consciousness of greater than 1 month, the sequelae of head injury are not perfectly correlated to the severity of cerebral insult.

Assessment of Injury Severity

What could account for this discrepancy? In order to draw conclusions regarding causality from an observed dose–response relationship, it is crucial that the measure of severity accurately reflects the injury. Alves and Jane (1985) suggest it is a lack of technology that accounts for the current impossibility to grade the severity of MHI accurately. Hynd (1988) also notes that behavioral effects can result from an injury that cannot be documented through conventional neurophysiological technology. In an early study of neuropsychological impairment in adults, the presence of certain types of neurological deficits increased the likelihood of an unsatisfactory recovery. The corollary to this finding was not evident, however; the absence of physical neurological abnormalities did not in any way guarantee good, much less complete, recovery (Klove and Cleeland, 1972).

At this time there is no universal classification for the severity of cerebral concussion (Binder and Rattok, 1989). This probably accounts for the fact that no single measure of injury severity is consistently applied (Gronwall, 1989; Levin and Eisenberg, 1979a, 1979b; Winogron *et al.*, 1984). The measures most frequently used—duration of coma, length of PTA, and the Glasgow Coma Scale score (GCS)—are often assigned by the review of medical records.

Retrospective assessment aside, each of these measures has intrinsic problems when applied to children. Duration of loss of consciousness, while regarded by some researchers to be an indication of severity of injury in adults, is not considered reliable in children (Boll and Barth, 1981; Ewing-Cobbs *et al.*, 1989). Many children experience very severe injury and do not lose consciousness.

The length of PTA is not a useful measure of cerebral insult in minor head injuries (MacFlynn *et al.*, 1984), The validity of this measure as a predictor of symptomatology and disability is problematic if the amnestic period is short. Fluctuations of the amnestic state itself and the unreliability of retrospective report make measurement difficult (Binder, 1986). This measures was not found helpful in estimating severity of deficits, rate of recovery, or personality changes in a study of adults sustaining MHI (O'Shaughnessy *et al.*, 1984).

The GCS, developed by Teasdale and Jennett in 1974, is purported to provide a highly reliable assessment of injury severity. This score is a composite rating of severity that considers the nature of the damage sustained. A study by Levin and his associates that used this index of severity has shown that the GCS may not be a valid measure in children having even severe head injury (Levin *et al.*, 1982). When used to assess mild injury in children or adults, the scale does not appear sensitive enough, and has no prognostic value for early or late complications (Kraus and Nourjah, 1989; Schoenhuber and Gentilini, 1989). The following two studies report on the use of the GCS with mild head-injured children.

In a retrospective study, Winogron *et al.* (1984) studied 51 children, ages 4–15 years, who had sustained head injury of varying severity. This study compared the pattern of deficits among the age- and gender-matched groups in order to determine the relationship between the neurological and psychological parameters of head injury. Instead of defining injury severity by PTA or coma duration, injuries were classified using the GCS. Scores of 7 or below indicated severe injury, and scores above 7 were combined with length of unconsciousness and presence or absence of neurologic signs established moderate or mild injury. All the youngsters were given the tests included in the Knights-Norwood Neuropsychological Test Battery approximately 1 year after injury.

To establish group differences in outcome, performances on psychological tests across the three severity groups were compared using one-way analysis of variance. Chi-square analyses were conducted to compare the frequency of psychological deficits (scores greater than 2 standard deviations below the mean) across the severity groups. Performance IQ and timed tests of motor speed, fine-motor coordination, tactual-spatial functions, and verbal fluency showed significant differences across study groups.

Automated profile matching, sensitive to levels of performance as well as to patterns of strengths and weaknesses, was also employed. Mean patterns of performance were compared for the three severity groups. Cohen's coefficient of profile similarity indicated that patterns of deficit for the mild and severe groups were least similar. The mild pattern resembled the moderate pattern to a slightly greater degree than the moderate pattern resembled the severe.

The most interesting section of the study with respect to the effects of MHI and the validity of the GCS again involved pattern matching by using the same statistic. From the original group, the 10 children having the profiles the most highly correlated with the average profile for each injury group were selected. The 10 youngsters selected by profile match were compared to see if profile match agreed with classification of injury severity. In the severe profile group, 7 children had actually sustained severe head injury. This means that 30% of the severe profile group consisted of children whose head injuries had been classified as mild to moderate by the GCS. These children showed similar deficits in IQ, tactual-spatial abilities, psychomotor speed, concept formation, sensory functioning, language abilities, and memory as the "average" severely injured youngster. In other words, head injuries defined to be of moderate to mild neurological severity did not consistently yield congruent patterns and levels of neuropsychological test scores.

Although preliminary in nature, a pilot study by Martini *et al.* (1990) concluded that children who incurred certain types of head injury considered mild as measured by the GCS ($\geq$ 13) have an increased risk of manifesting clinically significant neuropsychological and psychiatric sequelae 6 months following the injury. Sixteen children, ages 7–11, were administered the following neuropsychological battery: the WISC-R (except Vocabulary), Wide Range Achievement Test–Revised (RAT-R), Trail Making Test A and B, Grooved Pegboard Test, Logical Memory subtest of the Wechsler Memory Scale (immediate and delayed recall), Rey Complex Figure (copy and delayed recall), Wisconsin Card Sorting Test, and the Controlled Word Association Test. On the basis of a blind clinical rating of each protocol, 8 mildly head-injured children were classified as cognitively impaired. All the children were stratified into three groups based on presence of basilar skull fracture, nonbasilar injury with other complications such as hematoma, edema, or posttraumatic seizure, or no complications. Although the groups did not differ on Glasgow Coma score, there was a statistically significant difference in the proportion of impaired children in each group.

Psychiatric status was also evaluated with a series of structured interviews and questionnaires, including the Schedule for Affective Disorders and Schizophrenia for School-Age Children, Posttraumatic Stress Disorder Reaction Index—Child Revision, Children's Depression Inventory, Cognitive and Somatic State/Trait Anxiety Scale, Family Environment Scale, Family Inventory for Life Events Changes, and the Child Behavior Checklist. Results revealed a statistically significant association between biomedical variables and psychiatric disorder, in spite of the similarity of GCS scores. These findings not only question the prognostic utility of the GCS, but also point to the need for intervention and long-term follow-up in children with certain types of biomedical complications.

Recovery of Function

The literature discussed thus far has provided evidence that subtle neuropsychological deficits can occur with MHI in children and adolescents. Although numerous investigators have come to agree upon the *presence* of the neuropsychological sequelae of MHI, the *course of recovery* is still under contention. Some researchers suggest recovery is rapid and occurs within days or weeks (Levin, Mattis *et al.*, 1987; McLean *et al.*, 1984). The following studies provide information concerning the immediate and 6-month recovery of children and adolescents after MHI.

Short-Term Recovery. Levin and Eisenberg (1979b) assessed 45 hospitalized children and adolescents sustaining three levels of head injury. The study did not provide demographic information for the three severity groups. Neuropsychological assessment, completed before hospital discharge, included evaluation of language (Benton tests for aphasia), visuospatial and visuomotor abilities (Bender Gestalt design, block construction, and discrimination of faces), memory (Buschke's selective reminding procedure and a visual continuous recognition procedure developed by first author), somatosensory perceptions (Benton's test of stereognosis), and motor speed (electronic measurement of response latency).

Impairment in each major category was inferred on the basis of a defective performance, a score of at least 2 standard deviations below the mean for normal individuals of a similar age, on at least one of the tests making up that domain. Results of the neuropsychological testing suggested that for *each* major neuropsychological domain at least *one-third* of the patients were impaired during the early phase of recovery. Impairment rates for the mild group for each of the five domains included language, 20%; visuospatial skills, 14%; memory, 10%; somatosensory, 27%; and motor speed, 33%. In contrast, the severely injured group showed lowest impairment rate in the somatosensory domain (45%) and the highest in memory (86%). Across severity groups, the degree of neuropsychological deficit in the domains of language, visuospatial skills, and memory was directly elated to severity of injury.

Intellectual assessment was completed 6 months after injury using the WISC-R or the Weschler Adult Intelligence Scale. In contrast to the results of the neuropsychological assessment, these results revealed that persistent intellectual deficit remained for only the most severely injured youngsters. Almost all the children who had sustained loss of consciousness less than 24 hours recovered to an IQ of at least 85. This does not consider, however, the *premorbid* IQ level of the subjects.

At 6-months postinjury, 50% of the entire sample had memory impairment comparable to the fourth percentile in the normative sample. More specifically, the performance of the adolescents on a measure of acquisition of information and consistent long-term retrieval suggested a deficit even in the mildly injured group. Although the authors found that level of impairment in the areas of language, visuospatial skills, and memory were correlated with severity of injury, there was evidence of residual impairment in children with milder injuries. This study, then, identified deficits in cognitive functioning present in children and adolescents after hospital discharge that have obvious relevance for education and overall adjustment.

In a larger study, Levin and Eisenberg (1979a) evaluated 64 children and adolescents who had sustained head injury of three levels of severity. It is not clear if some of this group was made up of the previous sample. The test protocol was the same as that of the smaller study, but subjects were excluded if they manifested premorbid history of mental deficiency and school failure.

As found in the first study, results suggested that neuropsychological deficits were pervasive during the first 6 months after injury. In this sample, nearly half the sample exhibited impaired verbal learning and memory and/or continuous recognition memory. The presence of deficits was directly related to severity of injury; but, again, deficits were noted in some mildly injured children (language, 25%; visuospatial, 11%; memory, 21%, somatosensory, 25%; motor speed, 16%).

Most importantly, this study included a measure of premorbid intellectual functioning. As in the previous work, intellectual level at least 6 months after injury was within normal limits in all but the most severely injured subjects. Comparisons of current intellectual functioning with earlier group IQ scores obtained from school records of 12 children (injury level not specified) in the sample suggested, that only partial intellectual recovery was achieved by the end of 6 months. This result, however, may have been due to the tendency of group tests to overestimate IQ.

Other studies of both adults and children have also found recovery time of 3- to 6-months postinjury, and raise important questions regarding the full extent of recovery (Barth *et al.*, 1983; Barth *et al.*, 1989; MacFlynn *et al.*, 1984; Rimel *et al.*, 1981). Adams (1990, see p. 309, this Review) found statistically significant changes in academic achievement in head-injured children 2 years after injury. Barth and his colleagues (1986) and Gronwall (1989) maintain that although most individuals made a good recovery over 6–12 months, this recovery may actually be based on learning new coping skills, adapting, and becoming more comfortable with their disabilities rather than on full recovery of function.

Long-Term and Delayed Recovery of Function. At this time the long-range and delayed effects of MHI for both adults (Levin, Mattis *et al.*, 1987) and children (Levin *et al.*, 1989) are unknown. These authors note that skills undeveloped at the time of injury may appear to be spared, with evidence of impairment emerging only when the injured area matures. There are no studies, however, that have followed head-injured children throughout their development and investigated these changes.

Developmental Considerations

Interestingly, Boll and Barth (1981) believe that diffuse injury to the brain, the type most frequently seen in children and adolescents, may actually produce even greater developmental deficit than the complete focal absence of brain tissue. They explain, "The continuing presence of an impaired, but not at all silent, brain area exerting . . . abnormal influence may be far more deleterious to some . . . aspects of mental function" (p. 421). They elaborate several factors that make establishing the presence, nature, and degree of deficit difficult in children. First, children have no history of accomplishment that allows for the assessment of a baseline level of premorbid function. Second, year-to-year changes in psychological capabilities and style of performance are intrinsic to at least the first 12 years of childhood. This places a double demand on any attempt to assess the effect of brain injury. An assessment is required of both the *amount* and *type* of ability lost due to head injury at a time when prediction of the expected level of skills is the most difficult. To add to the complexity, the subsequent damage to the order, rate, and level of future development and learning capacity may skew the child's psychological course, even without a significant or permanent loss in premorbid skills. In other words, the effects of injury may be due not only to the neuropathological characteristics of the damage, but also to the *developmental tasks disrupted* at the time of injury.

It is for these reasons that Fletcher *et al.* (1987; Fletcher, 1990) take issue with studies failing to look beyond simple age effects. They feel neurobehavioral research of head injury in children must evaluate the determinants of change from the perspective of how growth and development proceed in an abnormal brain. The following study illustrates this point.

Ewing-Cobbs *et al.* (1987) studied linguistic skills to explore the effects of cerebral insult at various developmental levels. This study provides one of the only investigations emphasizing language functions in mild head-injured children and adolescents. The sample included 23 children, 5–10 years, and 33 adolescents, 11–15 years. Inclusion criteria included no history of previous central nervous system insult, adequate premorbid school performance, no evidence of neuropsychiatric disorder, no indication of child abuse, and recovery from injury to a testable level within at least 6 months. Twenty-three youngsters sustained mild injury, operationally defined by a normal computed tomography (CT) scan, loss of consciousness of less than 15 minutes, and absence of neurologic dysfunction. The remaining 33 children were classified as having moderate to severe injury.

The Neurosensory Center Comprehensive Examination for Aphasia or the similar Multilingual Aphasia Examination was administered within 5 months of injury (mean injury–test interval was 34 days). In order to examine specific domains of linguistic deficit and to reduce the number of dependent variables, the 11 subtests were grouped into naming, expressive, receptive, and graphic categories. The centile from each subtest was averaged to yield a composite score for each group.

A large proportion of the total sample exhibited clinically significant language impairment. At least 20% of both the child and adolescent sample exhibited deficits in naming and in expressive and written language. Written language, however, was more impaired in the younger group. The authors emphasized, "The finding that written language was disproportionately affected . . . is consistent with the hypothesis that skills in a rapid stage of development may be more affected by cerebral insult than well-consolidated skills" (p. 588).

Classification of children and adolescents based on level of severity of injury indicated the expected relationship between injury severity and level of impairment. More severe head injury was associated with depressed performance on the naming, expressive, and graphic composite scores. Receptive language was not significantly different from the group having mild injury.

The authors posit that even mild linguistic dysfunction may disrupt academic performance. Both the level of impairment noted in the total sample and the lack of any specific pattern of deficits shown in the individual linguistic profiles suggests that individualized evaluation is advisable following closed head injury of any severity level in children and adolescents who are returning to school.

This leads to the next section of the literature review, which discusses how the deficits associated with MHI might be expected to affect the learning process. First MHI is discussed in terms of an information processing model. Next, studies of memory are elaborated. The final section reviews studies that explore the academic functioning of children and adolescents with MHI.

Mild Head Injury and Learning

Information Processing

Several studies reviewed thus far have found evidence that MHI in children and adolescents can affect cognitive abilities that, in turn, impact academic functioning (Gulbrandsen, 1984; Levin and Eisenberg, 1979a; Martini *et al.*, 1990; Winogron *et al.*, 1984). These findings suggest that the effects of MHI might be understood within the context of an information processing model (Gentilini *et al.*, 1989). Indeed, Gronwall and Wrightson (1974, 1981) propose that the principal dysfunction in MHI is slowed information processing. Diffuse damage to the brain affects information processing capacity, i.e., how much and how rapidly information can be processed (Gronwall, 1989). Boll (1983) finds clinical evidence for information processing deficits in head-injured persons who have problems learning under complex conditions, functioning efficiently in novel circumstances, and coping with stress. Moreover, he suggests that these problems tend to exist in the absence of all other measurable difficulties and persist for several years.

Gronwall (1987, 1989) suggests that dysfunction of the attentional control system reduces the rate of information processing after head injury. Individuals frequently have difficulty with aspects of attention when they are required to analyze more items of information than they can handle simultaneously. They often appear to be slow, easily distracted, forgetful, and inattentive because of the extra effort required to process information. Alternatively Chadwick (1985) concludes that after head injury rather than there being a disruption of attention there is actually less attention available due to the increased time needed for information processing.

More recent research has concluded that attention is not a unitary concept and should not be investigated as such (cf. Mirsky *et al.*, 1991). Two studies of MHI in adults illustrate this point. In the first study (Gentilini *et al.*, 1985), persons having MHI and their matched controls showed no significant differences on global measures of attention. In contrast, when different aspects of attention (selected, sustained, divided, and distributed) were explored using the same sampling criteria and carefully matched controls, significant differences were found (Gentilini *et al.*, 1989).

Results of a study by Stuss *et al.* (1989) suggested that head injuries of varying levels of severity do result in deficits in both elements of attention and information processing rate in adults. A deficit of divided attention occurred in mildly concussed or *apparently recovered* individuals as well as those having more severe injury. It is of note that this study identified an impairment of focused attention and performance inconsistency across the groups; but this effect was observed only with repeated assessments using a focused attention task. In other words, optimal performance was *achieved* but could not be *maintained* by head-injured adults.

In view of the results of these adult studies, it is surprising that no studies could be located that consider how head injury impacts attention in children and adolescents. The following study, however, investigates the effects of stress on attention and memory in college students with a history of head injury.

Ewing *et al.* (1980) investigated attention and memory in college students exposed to stress. Students had experienced a head injury 1–3 years earlier; performance on tests of intellectual function had returned to normal. Length of posttraumatic amnesia was less than 5 hours for 90% of sample; no skull fracture, neurological localizing signs, or intracranial complications were present with injury.

Ten college students who had sustained a head injury and ten control students matched for sex, age, and academic achievement were tested by a technician blind to the head injury status of the students. First, each student took the Paced Auditory Serial Addition Task (PASAT) at ground level. Next, the student was exposed to a simulated altitude of 12,500 feet for 45 minutes. During this time each student performed the following 30-minute vigilance task. The student listened to a list of random single digits lasting either 6 or 9 seconds. The student was required to signal the end of each longer interval by reporting the number with which it ended. A memory task, running digit span, was incorporated with no warning into the vigilance task. At the end of this intrusion, the student was asked to report, in backward order, as many numbers as possible. Finally, the PASAT was readministered.

Results showed that under stressful conditions (i.e., mild hypoxia) students who had been concussed at least 1 year previously performed significantly below matched controls on tests of vigilance and memory. Scores on the PASAT, however, were not significantly different. In fact, both injured subjects and controls exhibited a practice effect and improved their performances under stress. In light of the results of the study by Stuss *et al.* (1989) discussed above, the use of a longer testing interval might have produced the expected group differences on the PASAT.

Studies of Memory

Historically, researchers have extensively investigated the effects of head injury on memory, especially with respect to posttraumatic amnesia, often used as a predictor of outcome. Many studies compare intellectual and memory deficits of severely injured children and adolescents to more mildly head-injured subjects (e.g., Levin *et al.*, 1982). Hence, no conclusions can be reached regarding the memory function of the mild injury group, who are assumed to be functioning normally.

As the information processing deficits connected with the full spectrum of head injury have come to light in the 1980s and as models of memory have become better elaborated, the focus of this research has shifted to the study of the aspects of memory that might be affected by changes in information processing capacity. A recent controlled study assessed memory function after MHI in adults with the California Verbal Learning Test (Zappala and Trexler, 1992). These authors found evidence of memory impairment consistent with subjective reports of many persons who have sustained only MHI. Memory impairment was found for verbal material in the immediate and delayed condition. In addition, organizational strategies used in retrieving information were affected by proactive interference.

Two studies that investigated impairment in memory, as well as other cognitive domains, are discussed earlier in this review (pp. 297-299); (Levin and Eisenberg, 1979a, 1979b). The following two studies investigated memory in head-injured adolescents.

Gronwall and Wrightson (1981) examined the relationship between information processing capacity, PTA, and memory impairment after injury of varying levels of severity in a group of adolescents and young adults (age range 17–30). Subjects were given the Wechsler Memory Scale, the Paced Auditory Serial Addition Task, and the Quick-test (an approximation of verbal IQ) 3–5 days after injury. First, the investigators formed groups using three severity levels based on duration of posttraumatic amnesia (PTA). Statistical comparisons using t-tests revealed no differences in Wechsler Memory Quotients between the mild (PTA $\leq$ 1 hour) and moderate (PTA 1–24 hours) groups. In contrast, when groups were formed according to PASAT scores, the Memory Quotients differed significantly across groups. Of particular note is the fact that of the 20 individuals whose injuries were classified as mild in terms of PTA, 10 showed moderate memory impairment and 2 showed severe memory impairment injury when classed by PASAT scores.

These data were explored further by using factor analysis. Rank correlation coefficients between all the measures were calculated and a Varimax rotated factor solution obtained. Three main factors that accounted for the score variance were isolated: attention and concentration, long-term memory storage, and retrieval from storage. This analysis suggested two different consequences of simple closed head injury. The first effect, measured by PASAT, related to Factor I—attention, concentration, and information processing capacity. The second effect, measured by PTA duration, involved learning and memory (Factor II).

In a related study composed of a younger sample, a visual form of the Continuous Recognition Memory Test, a measure that employs line drawings of familiar categories of living things, was used by Hannay and Levin (1988) to compare the performances of visual recognition memory of 91 head-injured adolescents and 46 normal control students. Although the head-injured students were screened for previous head injury, alcoholism, or other psychiatric disorder, it is not clear whether this was so for the control group. Head-injured subjects were classified into three groups according to injury severity. Severity was assessed by the Glasgow Coma Scale scores and presence of neurological impairment. A brief screening was administered to be sure that posttraumatic amnesia had resolved by the time of testing. It is unclear how soon after injury each severity group was tested; the range of injury–test interval was wide. For instance, one mildly injured adolescent was tested 9 days after injury and one severely injured youngster was tested 8 days after the accident. In view of the evidence of variable recovery rates at different severity levels, interpretation of the results is difficult.

Nonparametric statistics were used in analyses of the results due to the heterogeneity of variance in the test scores of the various groups. Results indicated that the performance on the Visual Continuous Recognition Test variables was not related to gender, education, or age for either the head-injured group or the normal control group. Results supported the sensitivity of this recognition procedure, which does not require a complex verbal or motor response for the evaluation of memory. Head-injured adolescents most consistently differed from controls with respect to the number of hits (correctly reporting having seen the stimulus previously) and the number of correct responses (correctly reporting having seen a previously presented stimulus or identifying an unseen stimulus as new). Severity of injury was significantly related to deficits in recognition memory.

One of the findings, however, is of particular interest to the review of the effects of milder forms of head injury in young people. About 9% of the adolescents sustaining such injury exhibited a residual impairment of continuous recognition memory defined as scores completely outside of the range for normal adolescents. This would seem especially significant because the injury-test interval varied from 1 to 75 days for the mildly injured group.

The authors cautioned that these results should not be extended to performance that involves recall of information, a different task. Interestingly, they speculated that attention is an important component of the Continuous Recognition Memory Test that demands sustained responding to a continuous presentation of pictures. If this proves to be the case, this test may be useful in screening head-injured students in order to predict readiness to return to school.

Information processing deficits affecting attention and memory in conjunction with developmental considerations discussed in the previous section, then, suggest that children and adolescents may experience consequences of head injury different from their adult counterparts (Boll and Barth, 1981; Fletcher and Levin, 1988; Gulbrandsen, 1984). One should keep this fact in mind when generalizing the results of adult studies to children.

The next segment of this article examines studies that investigate how MHI impacts the work of children, school performance. Both case studies and clinical research are reviewed.

Academic Performance

Early studies of children with MHI found evidence of deficits that persisted for at least several years and interfered with typical school performance (Black *et al.*, 1969; Klonoff *et al.*, 1977). It is noteworthy that, despite the importance of academic skills for adaptive functioning, few investigators have explored the type and severity of posttraumatic academic difficulties experienced by children or adolescents sustaining MHI. Chadwick (1985) suggests that poor school progress may reflect the cumulative effects of relatively minor cognitive deficits, compounded over several critical years. He reiterates that little is known about the factors underlying slow progress in school after childhood head injury. This is a remarkable observation, considering that much of the adult head-injury research centers on functioning after return to work.

An often cited early epidemiological study of 884 children having relatively mild head injuries revealed changes in both cognitive and psychological domains (Klonoff and Paris, 1974). In a complex follow-up study, Klonoff *et al.* (1977) evaluated a subsample of the same groups of injured children ($n = 231$) over a 5-year period. Performances were compared with age- and education-matched controls who were neuropsychologically normal. Although the classification of injury severity used in this study is criticized, most children appeared to sustain rather mild injury. Tests included the Reitan-Indiana Neuropsychological Test Battery for Children, two of Benton's tests, a lateral dominance test, the Stanford-Binet—Form L-M for children under age 5 or the WISC for older children. Children 9 years and older were given the Klove Motor Steadiness Battery.

Results identified persistent behavioral consequences of injury even among the mildly injured children. At 1-year postinjury, the sample showed neuropsychological impairment on over 50% of the tasks. One- and two-year testing intervals revealed impairment on 30% of the tasks. Klonoff *et al.* reported continuing evidence of impairment in a subset of the sample for as long as 4–5 years after head injury. Important to this present discussion of the effects of MHI on learning is the fact that by the end of the 5 years 25% of the entire sample of younger children either had failed an elementary grade or were attending remedial classes. About 70% of the older children who evidenced grade failure or withdrew from school had no premorbid history of school problems.

Fuld and Fisher (1977) reported a case study of a mildly head-injured child to illustrate the point that whether or not head injury *generally* leads to any intellectual deficit, serious impairment can occur in some cases. The boy, age 8 at the time of injury, had a history of normal social and intellectual premorbid development. There was, however, a family history of reading disability and reading problems. Head injury was judged to be quite mild (loss of consciousness of 15 minutes or less). The youngster was tested with standardized and experimental neuropsychological and psychoeducational tests a few months after injury. The battery included the WISC, the Raven Colored Progressive Matrices, the Benton Test of Visual Retention or the Beery-Buktenica Test of Visual-Motor Integration, the Saul R. Korey Memory and Learning Evaluation, the Gates-MacGinitie Reading Test, the Wide Range Achievement Tests, the Language Screening Battery, the Purdue Pegboard, the Kinsbourne and Warrington Test of Finger Differentiation, the Fuld Tests of Performance Consistency, the Gray Oral Paragraphs, and the Vineland Social Maturity Scale.

Fuld and Fisher reported that neither the mother nor the physicians were able to make an accurate judgment of the child's mental status. Neuropsychological testing indicated that continuing, serious posttraumatic intellectual impairments remained long after electroencephalograms and neurological examinations had returned to normal. Personality changes, which centered around an increase in aggressive behavior, occurred to some extent. Interestingly, these changes disappeared after cognitive, language, and motor functions improved. This case study indicated the presence of an interaction between social or academic functioning and mild injury that should be considered when evaluating individual cases and developing research protocols.

Slater (1989) reported similar problems in academic functioning following a MHI in an 18-year-old woman. She experienced only a 10- to 15-minute loss of consciousness, receiving a GCS score of 15 at the site of the accident; a CT scan evidenced no intracranial pathology. Her academic history was unremarkable for grade failure, learning disability, or remedial instruction. Evaluation with the WAIS-R took place at the time of injury, 6-months, and 1-year later. She was reported to be cooperative and concerned during testing. Although significant intellectual improvement occurred over the time course, a statistically significant WAIS-R score discrepancy of 24 points (PIQ > VIQ) was found at the final evaluation. This rather unexpected result may be due to the inability of the WAIS-R to reflect brain function adequately after MHI. Paradoxically, as she made cognitive gains during her recovery period, she became more psychologically distressed as measured by the Brief Symptom Inventory. This distress appeared to be related to an increasing awareness of her cognitive difficulties, which became evident when she entered college.

Noting that adolescents having head injury often experience difficulty after returning to the classroom, Slater and Kohr (1989) designed a study to compare the abilities of 33 injured teenagers to their noninjured peers immediately and 6 months after injury. The groups were matched for gender, race, and socioeconomic status. The head-injured sample included injuries of various severity levels as rated by the GCS. Eleven adolescents had sustained a severe injury, 3 received a moderate injury, and the remaining 20 incurred a mild injury. Parents provided a medical and school history through completion of a written questionnaire. Grade point average and English and mathematics grades during the year prior to enrollment in the study were obtained from school records for 43% of the sample. All students were administered tests of intelligence (WISC-R or WAIS-Revised) and academic achievement (Wide Range Achievement Test-Revised), a measure of oral reading (Gray Oral Reading Test), and a measure of receptive vocabulary (Peabody Picture Vocabulary Test). Only the head-injured group was tested at the 6-month interval; hence, there was no provision to control for practice effects.

The head-injured and control students did not differ with respect to SES, attainment of developmental milestones, neurological history, or presence of psychiatric problems. Although the sample size was smaller when measures of school functioning were compared, injured adolescents had a lower cumulative grade points and English grades than controls in the year prior to enrollment in the study. No significant differences were found in mathematics grades. Immediately posttrauma, injured students had lower Verbal IQ scores as well as poorer performances in spelling, arithmetic, oral reading, and receptive vocabulary than the controls. At the 6-month follow-up, injured adolescents had improved their performance on these measures. A difference remained, however, in relation to the initial test scores of the controls. The head-injured subjects continued to lag behind with respect to VIQ and in several areas of academic achievement (arithmetic, word recognition, oral reading, and receptive vocabulary).

These results lend empirical support to the case studies of Slater (1989) and Fuld and Fisher (1977), who hypothesized that some youngsters who sustain even milder forms of head injury experience a decline in intellectual and academic functioning. Preinjury testing was unavailable for the injured students in this study; therefore, the only conclusion that could be made relative to functioning 6 months after injury was that differences remained between the study and control groups. The conclusion that the premorbid academic functioning of the head-injured students was below that of normal controls was tentative due to the inclusion of only about 50% of the sample in that particular analysis.

Although the foregoing study does have implications regarding school reentry of head-injured students, it would have been more helpful if the injured groups had been homogeneous as to severity. The following study not only uses a homogeneous injury group but also includes a measure of preinjury academic functioning.

In this empirical study, Adams (1990) investigated the changes in levels of academic achievement approximately 2 years following MHI in 50 school-aged children. Appropriate baseline and postinjury cognitive measures were available due to annual statewide standardized academic testing in reading comprehension, spelling, math computation, and math application. In addition, sibling controls were used. Results suggested that following MHI persistent cognitive deficits remained long past the expected 3-month recovery period. Consistent with other studies that noted deficits related to complexity (Gulbrandsen, 1984) or less entrenched skills (Ewing-Cobbs *et al.*, 1987), deficits were most apparent on a complex mathematics task requiring reading, calculation, and novel problem solving.

In a recent descriptive study, Segalowitz and Brown (1991) administered a self-report questionnaire to 616 high school students in order to ascertain prevalence of MHI and to assess the relationship between such injury and developmental disabilities. Over 31% of the students reported that they had experienced a MHI and half of these reported some period of unconsciousness within the mild range. When the males were considered, results indicated a trend toward a significant relationship between head injury and remediation, and between head injury and grade repetition for those who had been unconscious. The entire group showed a relationship between mixed handedness and head injury; also, both hyperactivity and stuttering were related to unconsciousness. Although head injury alone did not show a relationship to school subject preferences, there was a significant relationship between unconsciousness and less favored ranking for mathematics. Discussing these results, the authors suggest that some of the attentional problems seen in older children may be in part due to head injury in childhood.

The studies reviewed have found evidence of both cognitive impairment persisting as long as 6 months and academic problems for up to 5 years after MHI in a small, but significant number of children and adolescents. In spite of this, there continue to be few studies that investigate the learning problems associated with MHI in students across their years of schooling.

Summary

This review of the head injury literature began with the empirical work of Rutter and his associates who proposed that the causal attribution of deficits directly to head injury in children could be made only if the head injury was severe. Deficits associated with milder forms of injury were considered qualitatively different from deficits associated with severe injury, and hence not comparable.

In contrast to the conclusions of Rutter *et al.*, other researchers hold that these deficits are a reflection of both the severity of brain trauma and an interaction with personality and social variables rather than an exclusively psychogenic syndrome. Although this review of MHI was complicated because the studies differed with respect to criteria of subject selection, etiology, time since trauma, pathology, or severity, both central processing deficits and neuropsychological impairments were evidenced in a small percentage of head-injured children and adolescents.

In some cases, diffuse injury to the brain appears to cause a reduction in overall speed, efficiency, and integration of mental processes. Deficits in information processing, attention, and reaction time are among the most overriding effects of head injury of any severity (Barth *et al.*, 1989; Boll and Barth, 1983; Ewing *et al.*, 1980; Gentilini *et al.*, 1985, 1989; Gronwall and Wrightson, 1981). Often referred to as "mental stamina," these deficits may be the cornerstone of the other cognitive impairments. Attention and concentration are domains that researchers suggest should be investigated more fully, especially in head-injured children (Barth *et al.*, 1983, 1986; Boll and Barth, 1983).

Information processing and memory are intimately linked. Studies of the different types of memory (verbal and nonverbal, immediate and long-term recall) in children sustaining head injury, however, are only beginning to be reported in the literature. Memory deficits associated with milder injury were noted by a number of researchers (Boll and Barth, 1983; Chadwick, 1985; Ewing *et al.*, 1980; Gronwall and Wrightson, 1981; Hannay and Levin, 1988; Levin and Eisenberg, 1979a, 1979b).

Chadwick (1985) suggested that speech problems in children are rare unless head injury is quite severe. Evidence of verbal and communication disorders, however, was found by several investigators (Boll and Barth, 1983; Ewing-Cobbs *et al.*, 1987; Levin *et al.*, 1987; Levin and Eisenberg, 1979a, 1979b).

Slater and Kohr (1989) found evidence of a lower VIQ in their study group. On the other hand, Chadwick (1985) observed a decrement in PIQ, but were unable to determine whether this decline was a function of specific visuospatial or perceptual deficits or due to generalized slowness in behavior and psychological functioning. Impairment of visuomotor function, psychomotor speed, and visuospatial skills have been noted by a number of investigators (Barth *et al.*, 1983; Boll and Barth, 1983; Gulbrandsen, 1984; Levin and Eisenberg, 1979a, 1979b; Winogron *et al.*, 1984).

Research suggests that a child's head injury can affect ability to learn new material, solve unfamiliar problems, and abstract information (Boll and Barth, 1983). However, children, who generally recover from physical injury more quickly than adults, often appear normal almost immediately after a MHI. Deficits may become apparent weeks or even years later as greater academic and social demands are placed on the child with compromised learning abilities (Barth *et al.*, 1986).

Although several investigations (Boll and Barth, 1983; Chadwick, 1985; Lein and Eisenberg, 1979a; Slater and Kohr, 1989) noted decreases in IQ after MHI, studies concerned with the educational consequences of such injury are few. Chadwick (1985) speculated that poor school progress may reflect the cumulative effects of relatively minor cognitive deficits, compounded over several critical years. Other researchers found that school functioning was, indeed, impaired in some children who had experienced MHI (Adams, 1990; Fuld and Fisher, 1977; Levin and Eisenberg, 1979b; Klonoff *et al.*, 1977; Klonoff and Paris, 1974; Segalowitz and Brown, 1991; Slater, 1989; Slater and Kohr, 1989). Rapidly developing skills may be more affected by head injury than well-established, automatic competencies (Boll and Barth, 1981).

The results generated by the study of head injury in the 1980s show that a prospective viewpoint toward head injury is essential. One cannot assume that a good recovery indicates a mild injury. It is not how *hard* one is hit, but the consequences of the injury that are important. The degree of severity of head injury required to produce documentable changes in mental function in both adults and children appears to be far less than previously thought (Sarno, 1980).

Just as this review has established that impairment can exist after MHI, it has uncovered several methodological problems that render the investigation of the effects of milder forms of head injury difficult.

REVIEW OF METHODOLOGICAL PROBLEMS

Methodological dilemmas in studies of head injury that attempt to establish cause of deficits are a salient aspect of this review of the literature and must be carefully considered when evaluating these works. Many investigators have directed attention to methodological issues (Bawden *et al.*, 1985; Gentilini *et al.*, 1985; Levin *et al.*, 1987; Miller, 1986; Rutter, 1981, 1982). In fact, Rosenthal and Berrol (1986) suggest that it is the inadequacies of methodology used in the assessment of MHI that may be responsible for the inability to confirm pathologic changes that would explain Postconcussion Syndrome. Because many persons who sustain MHI never seek medical attention, these problems are especially pronounced for studies that investigate the consequences of less severe head trauma (Goldstein and Levin, 1987; Jennett, 1989).

In the preceding review of the literature, four methodological issues are noted. First, the design of most studies is cross-sectional and many are retrospective. At the present time, Levin and his colleagues (1989) are continuing to report the results of their prospective, longitudinal study that obtained a baseline measure of neuropsychological functioning and followed children over time. The results of this study and those designed like that of Adams (1990; p. 309) are expected to clarify many of the questions that surround both the cognitive and behavioral effects of MHI. Studies are also criticized for lack of fixed or consistent follow-up intervals across studies, and variations in the choice of outcome end point (Alves and Jane, 1985). Furthermore, generalization of findings across studies is complicated by the differing criteria of injury severity and the variability of the neuropsychological functions examined (Miller, 1986).

The second issue involves utilization of a control group. Most, but not all, researchers stress its importance. Studies that use no matched control groups are criticized by Ruff *et al.* (1986). They point out that the effects of mild injury could be caused by premorbid characteristics such as history of alcoholism, polydrug abuse, neuropsychiatric disorder, or previous head injury. Rutter *et al.* (1983) caution that uncontrolled studies find intellectual and behavioral problems that cannot be unequivocally related to the injury.

There is also debate surrounding the selection of subjects. Studies of outcome after head injury have been criticized due to ambiguity of both subject and normal control selection criteria and variability in the compositions of sample population, especially with regard to age. Typical studies group injured subjects according to a severity index rather than by etiology (e.g., fall vs. motor vehicle accident) or pathophysiology (e.g., fractures vs. intracranial lesions) (Goldstein and Levin, 1987).

Barth *et al.* (1989) raise an interesting issue with respect to subject selection. They suggest that studies using a "clean" population may establish the cause of impairment but break down in generalizability because the overall clinical population itself is not free from confounding circumstances. That is, trauma is more likely to be sustained by individuals who may have had previous cerebral insult and/or dysfunctional social histories, and it is the effects of MHI in exactly this population that warrants further study.

Miller (1986) points out that many studies use hospital workers or student controls that could inflate group differences such as risk-taking behavior or "maladjustment" between head-injured individuals and control subjects. There is, however, consensus that persons who sustain head injury differ from the general population not only in terms of age and gender, but also on characteristics such as willingness to take risks, alcohol use, vocational choice, educational level, and psychosocial background. Because some of these variables are obscure and difficult to measure, several researchers have adopted a case-control pairing method that uses friends to form the control group (Gentilini *et al.*, 1985; McLean *et al.*, 1983, 1984).

Dicker (1989) emphasizes, "the population at risk for sustaining a head injury differs from a general population in a variety of subclinical or medically invisible areas (e.g., deficits in self-control or concentration)" (p. 74). She makes the strong recommendation that this procedure be adopted in all head-injury studies.

Another area that poses important considerations for the study of MHI the concerns the occurrence of spuriously negative results (Binder and Rattok, 1989). Gronwall (1989) and Marshall and Ruff (1989) suggest that a "we try harder" effect operates after MHI. In other words, individuals may become aware of limitations and exert more effort to overcome them. This is similar to the coping hypothesis suggested by Boll (1983), who advises that persons having MHI are able to produce normal behavior, but at increased cost. These authors feel, therefore, that the short, structured task demands of many tests may not reveal true effects of injury.

Ruff *et al.*, (1989) and Marshall and Ruff (1989) caution that group studies of mild head-injured individuals and matched controls merely reflect the significant differences between groups, and even then it is only longitudinal group studies using tests with high ceilings that provide an accurate reflection of recovery. Furthermore, group studies obscure subclinical impairment and detection of individual deficiencies. The need remains to identify and illustrate the subclinical deficits associated with head injury (Sarno, 1980). Studies based on normative data cannot be used to make discriminations on an individual basis. For instance, relative losses must be considered. If an individual who has previously functioned at the 95th percentile incurs a MHI and drops to the 65th percentile, it is likely that this decline will interfere with daily functioning.

Perhaps the most overriding criticism of the current neuropsychological investigations of head injury involves attempts to measure discrete variables in isolation from other deficits using instruments with little more than face validity (Adams and Putnam, 1991). Kane (1992) suggests that neuropsychological research has struggled to understand the effects of disease processes at the expense of research that evaluates the psychometric constructs of the assessment instruments. As a result, many investigators choose instruments with an incomplete understanding of what construct is actually measured. He elaborates: "We are still searching to understand the basic processes whose aggregate result is human intellectual ability" (p. 329).

CONCLUSIONS AND RECOMMENDATIONS

Current research suggests that there are consequences of MHI that can be devastating, especially to children and adolescents involved in learning. The studies reviewed here lend support to the judgment of clinicians who have begun to speculate that both the cognitive and emotional consequences of MHI should receive more serious evaluation (Kay, 1986). However, the lack of acknowledgment of the sequelae of injury by professionals in various fields has contributed additional frustrations and misconceptions that are difficult to rectify (Armstrong, 1987; Conboy *et al.*, 1986; Slater, 1989).

MHI should no longer be considered minor, especially in children and adolescents. We are far from a complete understanding of the posttraumatic sequelae of MHI in this group, but it appears that significant cognitive, emotional, and social problems can occur. Although the effects seen after MHI are neither as common nor disabling as those associated with severe injury, they are important to address because the *incidence* of MHI is so much greater.

Historically, the major research and clinical emphasis in the study of MHI in children and adolescents has involved the neuropathological, neurophysiological, and neuropsychological changes associated with injury The implied model of causation is medical, i.e., physical or objective signs underlie problems observed in individuals with MHI. Methodological considerations mandate that any study of injury that attempts to establish the cause of the observed deficits will be successful only if prospective, longitudinal designs are used.

These findings have helped clarify the possible mechanisms responsible for the acute effects; but they have made only limited contributions toward the understanding of the chronic effects of head injury and how these effects influence the basic task of childhood—learning. There are effects of MHI, whether organic or psychological, that might be studied from the standpoint of how they interfere with the learning at a particular developmental level.

This "injury" model and its methodology, although of proven utility for establishing causality of acute symptoms, may be too simplistic when applied to young people who are experiencing chronic sequelae. Persistent symptoms probably have multiple origins such as preexisting vulnerabilities, head-injury related losses, and the reactions of others to those losses. All of these must be taken into consideration when planning treatment interventions. In other words, instead of debating the *causes*, it may be time to seek a more comprehensive understanding of the *effects* with an eye toward identification and the development of treatment interventions.

In 1983, Boll suggested that the "cognitive and emotional changes resulting in reduced capacity to cope with one's world are, at once, the most *disruptive* and the most *disputed* consequences of mild head injury" (emphasis added, p. 74). He elaborated the need for an increased understanding on the part of psychologists, pediatricians, and educators who come into contact with individuals who have sustained a MHI. Yet today, 10 years later, neuropsychologists are just beginning not only to understand, but also to enlighten others regarding the pervasive effects of an injury that often remains silent, unseen, and unappreciated by many professionals.

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