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HANDICAPS AS A CONSEQUENCE OF
SEVERE HEAD INJURY IN CHILDREN

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Neuropsychological And Behavioural Handicaps As a Consequence
of Severe Head Injury in Children

by

H. William Winogron

Thesis submitted to The Faculty of Graduate Studies in
partial fulfillment of the requirements for the degree of
Master of Arts

Department of Psychology

Carleton University

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The undersigned recommend to the Faculty
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ABSTRACT

Three groups of children sustaining neurologically mild, moderate, and severe head injuries were compared on a battery of neuropsychological tests. The groups were balanced for age and sex. Performance I.Q. and timed tests of motor speed, visuospatial and tactual-kinesthetic functions, current adaptive abilities, and verbal fluency showed significantly greater deficits for severely injured Ss than for mildly or moderately injured groups. Relations between neurologic indices of injury severity and psychological outcome measures were investigated; Glasgow coma severity scores and duration of altered consciousness were related to performance on several major neuropsychological functions. Intracranial pressure measures were unrelated to outcome, and behavioural ratings post-trauma did not vary with severity of injury. Comparisons of neuropsychological profiles indicated that the pattern of deficit after severe head injury is more distinctive than those after mild and moderate injuries. Deficit patterns were least similar for the mild and severe groups, and were most similar for the mild and moderate groups. Results were discussed in terms of their prognostic usefulness, and suggestions were made for the future study of neurologic-psychologic relations after head injury.

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INTRODUCTION

The care of children with developmental handicaps requires a long term commitment from medical and educational specialists as well as from the children's families. Head injury is a common cause of developmental handicap and the frequency of head injuries has increased in the past two decades (Nelson, Vaughan & McKay, 1979). At the same time, advances in the medical maintenance of head-injured patients have decreased mortality rates, allowing the survival of individuals with varying degrees of neurological and psychological impairment. The care and subsequent rehabilitation of these patients is of central concern to a variety of professionals, and the value of being able to predict and influence outcome soon after head injury had been emphasized by medical practitioners, psychologists and educational specialists.

The proposed study investigates the effects of mild, moderate and severe head injury upon the development of children's neuropsychological and behavioural handicaps. Three patient groups are evaluated and compared in this research; One of the groups consists of subjects having sustained severe head injuries followed by varying intervals of coma. These subjects have undergone continuous monitoring of intracranial pressure (ICP), as part of an aggressive

treatment regimen aimed at controlling ICP and thereby reducing secondary brain damage. A second group consists of subjects sustaining moderate neurological injuries, while the third group is composed of children sustaining neurologically mild head injuries. This research attempts to relate group differences in acute neurological status after head injury to the subsequent development of handicaps. The analysis of differences in group outcome may allow the determination of those factors which are relevant to eventual outcome in cases of paediatric head injury.

REVIEW OF LITERATURE

The Relevance of Information From Adult Studies of Neuropsychological Deficit After Head Injury to Studies of Children's Head Injuries

In a recent, extensive study of the pathophysiology of head injury in children Bruce, Raphaely, Goldberg, Zimmerman, Bilaniuk, Schut, and Kuhl (1979) demonstrated "a pathophysiological response of the brain to trauma that seems to be almost unique to children and adolescents". (p.85). The response involves diffuse swelling within the brain soon after injury, caused by increased blood flow and blood volume (hyperemia and vasodilation). This response differs drastically from the decrease in blood flow typically observed in comatose adults following head injury (Obrist, Langfitt, ter Weeme, et al. (1977)).

Bruce, Schut, Bruno, Wood, and Sutton (1978) have argued that children have a lower threshold for neurophysiological dysfunction. This means that an equal force impinging on a child's brain and an adult's brain will cause a worse clinical-neurologic picture in the child.

As a result, a clinical state, as reflected in a coma severity score for example, which in an adult is associated

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with severe injury and poor prognosis, may be associated with less injury in the child's brain, and may therefore be associated with better prognosis for the child.

The fundamental differences in the pathophysiology, and resultant treatments of head injury in children and adults prohibits simple generalization of findings from adult studies to those of children.

Throughout this research some mention is made of adult findings as they relate to studies of children. However, a review of the information concerning neurologic-psychologic relationships in adult head-injured populations is beyond the scope of this research.

PERSONALITY OR BEHAVIOURAL DISORDERS FOLLOWING INJURY

Personality disorders following severe head injury in children have included reports of clinical psychiatric judgements as well as larger, more standardized psychological follow-ups.

The clinical psychiatric reports have yielded discrepant findings: Ssouchareva and Einhorn (1935) found that 16 of 30 head-injured children showed persistent psychiatric disturbances more than one year after their injuries. Similarly, Dillon and Leopold (1961) found that 47 of 50

head-injured children, having sustained at least a brief duration of unconsciousness (often of indeterminate duration), showed psychological changes, including withdrawal, aggression, disobedience and poor self-control, as long as one year after injury. On the other hand, a number of studies have reported substantially lower rates of disturbance. Ridgenbach (1946) found lasting psychiatric symptoms in only six of 167 head-injured children examined six months to ten years following trauma. In Lutz's (1951) sample of 24 head-injured children, symptoms of neurologic and psychiatric disorder were observed in only two children; Lutz (1951) considered this finding representative of the previously-published literature. Harris (1956) found psychological changes after head-injury in only 13 per cent of his cases, and others (Blau, 1936; Selley, 1958) who have reported cases of acute psychosis post-injury, have considered such developments rare.

The behavioural disorders and psychiatric symptoms stressed in the above reports include psychopathic personality traits, headache, sleep disturbances, impulsiveness, emotional lability, depression, suspicion, irritability, truancy, violence and theft. Discrepancies in the rate of disorder reported by certain of the above authors have been attributed (Harrington & Lettem, India, 1958) to differences in the selection of patients across studies;

whereas some samples were drawn from referrals to a psychiatric clinic (eg. Ssouchareva & Einhorn, 1935), others were selected from surgical referrals (eg. Riegenbach, 1946) or a combination of these sources (eg. Lutz, 1951). Different premorbid rates of behavioural and intellectual disturbance among these groups may account, to some extent, for the discrepant findings.

Harrington and Letterendia (1958) examined the differences in long-term psychiatric sequelae in children referred to a psychiatric clinic post trauma with those referred to a surgical clinic. Although the head injuries in the latter group were more severe in terms of presence of cranial fracture, duration of unconsciousness, and neurologic sequelae, this group showed fewer psychiatric disorders at long-term follow-up. Pretraumatic intelligence and personality, and family background were found to be more important for outcome than was the nature or severity of injury. The importance of pretraumatic personality factors as determinants of outcome has also been described by others (Crothers & Lord, 1938; Fabian & Bender, 1956; Riegenbach, 1946).

More highly standardized follow-up studies of children sustaining severe head injuries have also been conducted. The most commonly reported symptoms among these studies include nervousness, and bad temper or poor self-control.

However, methodological differences among these studies (described below) again prevent a simple or unitary interpretation of the findings.

Beckman (1928) followed-up 234 children under 13 years of age who had sustained cranial fractures or head injuries followed by unconsciousness. Five per cent of this sample showed sequelae one to two years after trauma. Of these, six cases showed steady improvement, while five were described by teachers and parents as being quarrellsome, sullen, and uncontrollable. In a similar but smaller sample, Ireland (1932) found a comparable rate of deficit (four per cent) but found that sequelae consisted solely of headaches.

In a follow-up study of 100 children sustaining head injury between the ages of one and 12 years, Rowbotham, Maciver, Dickson and Bousfield (1954) reported that 30 children showed at least one of the following symptoms, two to three years after injury: faulty memory, poor concentration, nervousness, bad temper and enuresis. The relationship of these symptoms with premorbid status and severity of injury was not considered and the authors were unable to assess the origin of the disturbances.

Behavioural problems centering around poor self-control have also been reported in two more recent studies: Burkinshaw (1960) evaluated the outcome from severe head injury in a sample of 135 children by means of parental

questionnaires. Twenty per cent of this sample showed personality changes including nervousness, moodiness and hostility. These changes were unrelated to coma duration, and no attempt was made to account for their occurrence.

Black, Jeffries, Blumer, Wellner and Walker (1969) found in a short-term prospective study of 105 children, that behavioural abnormalities occurred within one year after trauma in 31 per cent of patients who had not previously had any psychiatric disturbances. The most frequently observed symptoms were poor anger control and hyperactivity.

In a recent, and particularly extensive study, Schaffer, Chadwick and Rutter (1975) examined the psychiatric outcome after localized head injury in a group of 98 school children. These children, between five and 17 years of age at the time of injury, were examined a minimum of two years after having incurred unilateral compound depressed skull fracture.

A broad range of assessment procedures was employed by these authors. They compiled a global rating of psychiatric disturbance from interviews with children and their parents, and from ratings on a teacher questionnaire. Head-injured children showed a very high rate of psychiatric disorders (62 per cent were affected at follow-up) however, the results failed to demonstrate a relationship between disorder, age, and locus or severity of injury. WISC-R IQ was unrelated to age or locus of injury, but was negatively related to loss of

consciousness exceeding 72 hours. This latter finding is consistent with other results (Heiskanen and Sipponen, 1970). It was also concluded that the likelihood of psychiatric disorder was substantially increased by poor home environment.

In reviewing the above follow-up studies, little consensus can be reached. These studies of behavioural or psychiatric disorder following severe head injury have yielded greatly variant rates of deficit ranging from less than four per cent to approximately 62 per cent. The discrepancies may be due, at least in part, to differences in the severity of injury incurred by children in different samples, and due to differences in the injury-test intervals employed in different studies, and to different methods of assessment.

It appears that children sustaining severe head injury are at greater risk for personality disorders than children in general. However, recovery or compensation appear to occur over time; persistent disorders seem to be rare (Rune, 1970). Interestingly, indices of the severity of injury have not been successfully related to the rates of subsequent deficit. Furthermore, premorbid personality, family, and environmental factors appear to be contributing factors in the development of post-traumatic disorder.

STUDIES EMPLOYING COMA DURATION AS A PROGNOSTIC INDICATOR
FOLLOWING HEAD INJURY

Impairment of consciousness is a frequent and easily observed concomitant of head injury, particularly severe head injury, and has been employed widely as a measure of the nature and severity of brain impairment. Smith (1961) surveyed the early literature on the duration of unconsciousness (in children and adults), concluding that in cases of head trauma without focal signs, increased duration of unconsciousness was the most reliable single index of severity of injury. He also found that increased unconsciousness was associated with increased cognitive impairment. In assessing these results, Smith (1961) stressed the diversity of the studies considered. It was emphasized that differences in populations, injury-test intervals, follow-up examinations, and the definitions and measures of coma employed, were all important factors in the assessment of these results. In general, the findings indicated that outcome varied as a function of age, with young patients showing less drastic deficits.

A more recent study of prognosis following head trauma (Overgaard, Christensen, Hvid-Hansen, et al., 1973) examined outcome from blunt head injury in groups of patients both above and below 30 years of age (108 of these patients were

under age 20 years). This research reported outcome two to three years following injury in terms of a patient's ability to resume pre-traumatic activities without limitation. The groups were matched for presence of coma and abnormal motor patterns. Results generally indicated that increasing age was associated with poorer recovery, with coma being the most important unfavourable sign for adult patients.

Although recovery from coma subsequent to severe head injury is generally considered to be better in children than adults, knowledge of the rate and extent of recovery in children is difficult to assess. This is, in part, because of the heterogeneity of patients and injury-test intervals utilized, and because of the variability in assessment procedures employed.

Two studies of children (Carlsson, von Essen & Lofgren, 1968; Hjern & Nylander, 1962), which examined the late prognosis of severe head injury followed by coma, failed to find a relationship between coma and subsequent adjustment. However, these studies employed extremely variable follow-up intervals and may have employed inadequate classification of patients.

Hjern and Nylander (1962) examined the late prognosis of severe head injury in children injured between the ages of one and 14 years. Evaluations were conducted six months to nine years after injury. Of the 22 patients followed-up

after coma, lasting one to 50 days, seven patients showed remarkable neurologic sequelae, only one showed psychiatric sequelae (at six months), and five showed both types of sequelae. No certain correlation was found between the duration of unconsciousness and the degree of severity of symptoms. However, this negative finding is limited because patients in coma exceeding 24 hours were not separated from those in coma over seven days.

Carlsson, et al., (1968) examined the relationship between the probability of restitution (resumption of work or active rehabilitation) and coma duration in patients having been comatose for at least 12 hours following head injury. At follow-up examination, one to 10 years following trauma, they found restitution occurred in nearly 100 per cent of those injured prior to age 20 years, "irrespective of the duration of coma" (p.251). However, this statement cannot be generalized since a number of patients in this age group probably experienced relatively mild head injuries, and only three patients of 98 in this group experienced coma exceeding seven days.

Subsequent studies examining the outcome from post-traumatic coma, have demonstrated an association between post-traumatic coma and readjustment. Pazzaglia, Frank, Frank and Gaist (1975) assessed the social reintegration of 112 patients a minimum of two years following head injury

with coma exceeding 24 hours. Their classification of coma included patients who were strictly comatose and those who were stuporose (arousable unresponsiveness). Passaglia et al., (1975) found that of the 88 patients under 20 years of age, 45 made complete reintegration into their pretraumatic social lives, eight were partially reintegrated or not reintegrated, and 35 children died. The percentage of patients recovering who were under 20 years of age was substantially higher than the rate for those over 20 years of age.

Stover and Zeiger (1976) examined the relationship between coma duration and functional recovery after head injury in children aged two to 19 years. Results indicated that none of the patients, all of whom were in coma longer than seven days, showed complete recovery of pre-injury personality, physical or psychological status. Whereas the majority of patients in coma for less than three months achieved independent ambulation, coma exceeding four months was not usually associated with independent living.

The studies described above have reported the effects of head injury upon primarily the social and behavioural adjustments of the individuals affected. The majority of the studies subsequently reviewed have evaluated a broader range of human functioning, in some cases by means of comprehensive neuropsychological testing. In several studies, coma

duration has been incorporated as an independent measure, thereby potentially increasing the comparability of the obtained findings.

NEUROPSYCHOLOGICAL DEFICITS AND ACADEMIC PROGRESS FOLLOWING HEAD INJURY

Intelligence Measures

Among tests of neuropsychological functioning after head injury, the I.Q. test has been the most commonly administered. Richardson (1963) reported that moderate deficits in I.Q. (10-30 points) and greater than normal dispersions of subtest scores were typical two to 14 years after prolonged coma in children with severe concussion. Coma duration in this sample of 10 children ranged from seven to 47 days with a median of 28 days. Although EEG recordings for all patients showed some abnormalities, no relationship was found between EEG and behavioural, or intellectual abnormalities.

The same pattern of I.Q. deficits was observed in 80 per cent of 146 severely head injured children followed-up by Flach and Malmros (1972). These authors found I.Q. changes to be the most frequent deficit at the time of follow-up.

which varied from eight to 10 years following trauma.

Klonoff and his associates (Klonoff, Low & Clark, 1977; Klonoff, Robinson & Thompson, 1969) have compared I.Q. levels in head-injured children with those of normal and chronically brain damaged controls. In the first study (Klonoff et al., 1969) 74 head injured children, aged three to nine years, were compared with a chronic brain-damaged group and with normal controls. Both clinical groups were found to have mean I.Q.s significantly lower than their respective controls. Children in the head-injured or acute group, were categorized according to their neurologic diagnoses at admission. However, the relationship between neurologic and neuropsychologic measures was equivocal.

Klonoff et al., (1977) examined 117 children at the time of their injuries and then yearly for five consecutive years following injury. They found that head-injured children, both above and below nine years of age, showed significant deficits in I.Q. relative to matched normal controls. And, although no reasons were postulated for the trend, improvements in I.Q. over time were intermediate between neurological recovery (slowest) and E.E.G. recovery (fastest).

Fuld and Fisher (1977) on the other hand, found that serious intellectual impairments measured on the revised Wechsler Intelligence Scale for Children persisted long after

E.E.G and neurological deficits returned to normal. However, these results are difficult to evaluate because their sample consisted of only 18 children, and results were presented for only seven cases, of which only two were detailed.

Brink, Garrett, Hale, Woo-Sam and Nickel (1970) followed the recovery of intellectual function in a group of 46 severely head-injured children between the ages of two and 13 years. The criterion for inclusion in the study was coma duration of at least one week, and the average coma lasted seven weeks. Intellectual level and academic performance were impaired in a majority of the patients, and intellectual deficit was found to be greater for children under age 10 years. In addition, a definite negative correlation was found between coma duration and post-injury intelligence measures. Although this latter finding is consonant with that of Schaffer et al. (1975), Heiskanen and Kaste (1974) have found that coma of relatively brief duration (3-4 days) in some cases results in a severe decline in intellect.

Other Measures of Neuropsychological Deficit

Brink et al., (1970) found the most common motor deficits after prolonged coma in their sample of 46 children were spasticity and ataxia, observed in 93 and 70 per cent of

the sample respectively. They reported that at least partial recovery of motor skills was shown by all patients who regained consciousness, including those in coma exceeding three months. In terms of family adjustment, the patients' residual physical disabilities were seen as less problematic than the aggressive, impulsive and destructive behaviours they exhibited. Other sequelae reported included sensory deficits, visual disturbances and speech abnormalities. The relearning of intelligible speech was found to parallel the recovery of motor functions.

The research by Klonoff and his associates has employed the test battery approach to neuropsychological evaluation following head injury. Klonoff et al. (1969) found that neuropsychological impairment on the Reitan Neuropsychological Battery for Children was extensive and generalized; 16 of 18 tests and 24 of 32 variables differentiated head-injured patients from their matched normal controls. Also, a discriminant analysis significantly distinguished between the patterns of neuropsychological deficits in the head-injured group and deficit patterns in a chronic brain-damaged group.

Severe neurologic impairment and abnormal E.E.G. were found in 50 and 59 per cent of the head-injured group respectively. However, the relationship between the neuropsychological impairment index and the measures of

neurologic and electroencephalographic impairment failed to reach significance.

The five-year longitudinal study by Klonoff et al. (1977) showed that recovery on neuropsychological tests was faster than neurological recovery, but slower than recovery of normal E.E.G. The study demonstrated that performance on the Reitan-Indiana Neuropsychological Battery For Children showed continuous improvements across all five years, with 25 per cent of the children under age nine years and 21 per cent of children above nine years of age showing impairment at final follow-up. It is noteworthy that maximal improvements occurred within the first year after injury.

Fuld and Fisher (1977) employed a wide range of intellectual assessment procedures including measures of I.Q., achievement, memory, and comprehension. However, for reasons discussed above, their results are not clearly interpretable.

Measures of Scholastic and Social Deficit

A number of outcome studies have evaluated scholastic progress and social readjustment following severe head trauma. Richardson (1963) found that two to fourteen years following severe concussion with prolonged coma, rote memory

defects resulted in academic and social maladjustments. The academic difficulties reported, were too varied to allow an analysis to be undertaken.

Flach and Malmros (1972) evaluated school adjustment by means of parental questionnaires, and measured social adjustment in terms of a patient's educational, occupational and social position relative to that of his or her family. These researchers found that 27 per cent of 131 surviving patients followed-up were socially maladjusted. The correlation between social adjustment and school questionnaire findings was found to be quite high, however the relationship between social adjustment and psychological test results was less distinct.

Whereas over 75 per cent of the school-attending children studied by Brink et al. (1970) required special educational placement post-injury, Klonoff and Paris (1974) found that academic performance declined from pre-morbid levels in only 13 per cent of children sustaining head injury with brief or no loss of consciousness. A follow-up of these children (Klonoff & Low, 1974) indicated substantial improvements on Wechsler IQ and neuropsychological tests after one year. It has been suggested (Levin & Grossman, 1976) that differences between these series may reflect a difference in the distribution of coma severity scores.

Heiskanen and Kaste (1974) evaluated neurological

deficits and school adjustment in 36 children having sustained severe head injuries before age 16 years. All children had coma exceeding 24 hours and the median coma duration for the group was nine days. Follow-up was conducted between four and 10 years after the trauma, and results showed that children who were in coma longer than two weeks in almost all cases, did not make normal school progress.

STUDIES EMPLOYING THE GLASGOW COMA SCALE AS AN INDICATOR OF SEVERITY OF INJURY

One of the major difficulties in comparing outcome after head injury among different patient populations has been caused by differences in the clinical neurologic criteria used to classify patients. In order to more adequately describe the acute neurologic status of head-injured patients, Teasdale and Jennett (1974) introduced a standardized 14-point scale of coma severity called the Glasgow Coma Scale. The scale is presented in Appendix 1, and is discussed below.

The Glasgow Coma Scale

A variety of methods exist for the classification of coma. Teasdale and Jennett (1976) have argued that most are inadequate due to one or more of the following deficiencies: 1) The division of the spectrum of altered consciousness into a number of arbitrary steps when there are "no clear watersheds in the continuous spectrum of responsiveness between deep coma and full consciousness" (p.46). 2) Dependence upon specific anatomical-clinical correlations despite evidence (Mitchell & Adams, 1974) that severe blunt trauma often results in widespread cerebral lesions. 3) For most scales, there exists no evidence of inter-rater reliability.

The Glasgow scale was introduced to remedy these shortcomings. It measures responsiveness in three different areas: eye opening, best verbal and best motor responses. In each of these areas, well defined criteria are used to grade responses indicating the degree of dysfunction. Arbitrary boundaries between different "states" of consciousness are thereby avoided. Also, the three-response system does ~~not~~ necessitate assumptions of specific underlying lesions or mechanisms. The three sub-scales of the Glasgow scale were chosen in part because of the variability of possible responses and because of the ease of response elicitation in these areas, and because verbal and motor measures were included in virtually all of the coma scales reviewed by

Jennett and Teasdale.

Langfitt (1978) has stated that coma scales must be clear and simple to reduce inter-rater variability. Because coma scales are often employed by inexperienced hospital staff, they must be easily administered and scored.

The simplicity and clarity of the terms employed in the Glasgow scale were assessed by Teasdale, Jennett and Knill-Jones (1974). They presented filmed motor responses to clinical workers -- thereby eliminating differences due to examination procedures -- and found agreement rates as high as 97 per cent. The disagreement rate for the same group of assessors jumped to 15 per cent when they were instructed to label the filmed responses as "purposeful" or "not purposeful," as is required by several scales.

The reliability of the Glasgow Coma Scale as a whole, in normal test circumstances, was also reported by Teasdale et al. (1974). They found inter-rater agreement among a sample of doctors and nurses to be 94 per cent for the motor scale and 91 per cent for the remaining two scales. In contrast, the disagreement rate rose to 20 per cent when these raters categorized the same patients as being simply "conscious" or "unconscious."

A measure of the scale's internal consistency is provided by Levin and Eisenberg (1979) who found the relationship between verbal and motor scores to be highly

significant in a sample of 64 head-injured children. These authors considered the findings as evidence that the two scores were "manifestations of a common neurologic state." (p.283)

The validity of the assumptions that the three Glasgow sub-scales should receive equal weighting, and that equal-weighting should be assigned to each step within each of the sub-scales has not been tested formally. However, Jennett et al. (1977)* compared the relationships between GCS scores and outcome in three centres, in three countries, and found similar morbidity and mortality rates for patients with the same GCS scores in all three centres. These findings confirm to some extent, that the GCS is a valid measure of injury severity.

Since its introduction, the scale has been employed in studies of head injury in both children and adults. Use of this standardized scale has provided a potential means of overcoming the difficulties of patient classification encountered in earlier studies.

Bruce, Schut, Bruno, Wood and Sutton (1978) examined 53 subjects, under age 17 years who were rated as severely injured on the Glasgow scale. Evaluation of outcome after a minimal interval of six months revealed that all patients who did poorly or died had less than four points of a possible 14

on the coma scale at the outset of this study, while those scoring five or better showed some improvement. Ninety per cent of the subjects showed good recovery or only moderate disability at six months after their accidents. The low morbidity rate in this series was attributed in part to the continuous monitoring and aggressive neurosurgical control of intracranial hypertension, a major cause of death in cases of paediatric head injury (Lindberg, Fisher et al., 1955).

Braite, Raphaely, Goldberg, Zimmerman, Bilaniuk, Schut and Kuhl (1979) employed a similar program of active neurosurgical therapy in order to prevent secondary brain injury due to intracranial hypertension. These researchers evaluated outcome following severe head injury (Glasgow Coma Score of eight or less) in 85 children between the ages of four months and 18 years. They reported mortality, morbidity, and recovery rates very similar to those of Bruce et al. (1978): Overall mortality rate was 9 per cent with 3.5 per cent remaining severely disabled or in a persistent vegetative state. Approximately 88 per cent of patients showed good recovery or only moderate disability, and Glasgow coma scores greater than five points were always associated with good recovery.

In a study of neuropsychological outcome after blunt (non-missile) head injury, Levin and Eisenberg (1979) quantitatively assessed a variety of neuropsychological

functions in 64 head-injured children and attempted to relate these to neurologic indices of the injuries. Testing was conducted after post-traumatic amnesia subsided, and the median injury-test interval and range were 19 days, and one to 185 days. Memory was the most commonly impaired neuropsychological function with 44 per cent of all subjects showing a deficit in verbal learning and memory, or continuous recognition memory. Approximately 30 per cent of all subjects were impaired in each of the remaining test areas.

Deficits in memory and visuospatial ability were positively related to coma duration and severity of injury as determined by the verbal component of the Glasgow Coma Scale. Conversely, measurable neuropsychological deficits (language, somatosensory ability, motor speed) occurred in patients experiencing brief coma or no loss of consciousness. This finding is consistent with the findings of previous research (Klonoff et al., 1977).

Unequivocal impairment of intellect, ie. I.Q. below 70, occurred in only four of the most severely injured patients (coma exceeding 24 hours). In the remaining cases, I.Q., which was assessed at least six months post-injury, was within the normal range. However, comparisons with pre-morbid ability levels, where available, revealed that only partial recovery was usually attained. Linguistic

deficits were present in 31 per cent of subjects. This rate is lower than that reported for adults recovering from closed head injuries (Levin, Grossman & Kelly, 1976) and supports Hecaen's (1976) finding of more rapid recovery from acquired aphasia for children than for adults.

PROBLEMS INVOLVED IN THE EVALUATION OF THE SEQUELAE OF HEAD INJURY

The comparison of findings among studies examining the outcome from severe head injuries in children is difficult as a result of the number of methodological inconsistencies. One such inconsistency exists in the screening of patients with respect to premorbid history. For example, Fuld and Fisher (1977) in their study of 18 head-injured children, saw only three patients who could be described as socially and academically normal prior to their accidents. The premorbid problems ranged from learning difficulties to severe delinquency and mental retardation. Other researchers (eg. Levin & Eisenberg, 1979) have limited participation in their studies to patients with negative antecedent history for neuropsychiatric disorders. To the extent that the premorbid factors affect the various outcome measures employed in the above studies, useful comparison of results may be

confounded. The contribution of premorbid factors to outcome following head injury has been particularly well demonstrated in studies of psychiatric follow-up (Harrington & Lettemendia, 1958).

Another inconsistency involves the use of coma severity or coma duration as an independent measure of severity of head injury. There exist numerous definitions and classifications of levels of consciousness with little agreement in clinical practice (Stover & Zeiger, 1976). These differences in the classification of subjects detract from the comparability of the studies, however, the widespread adoption in recent years of the Glasgow Coma Scale (Teasdale & Jennett, 1974) has allowed standardization of coma classification and has therefore increased comparability, at least among more recent studies.

Another inconsistency is perhaps the most important; Levin and Eisenberg (1979) have reported that neuropsychological studies (eg. Klonoff et al., 1977) have inadequately classified the severity of the neurological deficits of subjects. Alternatively, neurological studies (eg. Bruce et al., 1978) have described outcomes solely in terms of gross categories of adjustment. The lack of consistency in classification systems and the use of different dependent and independent measures of impairment and adjustment make comparisons across studies difficult.

The recent use of the Glasgow Coma Scale and intracranial pressure monitoring techniques provide additional methods of neurological assessment, while the use of standardized child rating scales and detailed neuropsychological assessments provides good measures of adjustment and ability levels. Comparisons of these two types of data should provide new information regarding head injury and its sequelae.

SUMMARY OF CURRENT KNOWLEDGE REGARDING THE CONSEQUENCES OF HEAD INJURIES IN CHILDREN

Despite the methodological inconsistencies described above, studies of recovery and outcome from head injury have had at least limited success in isolating certain variables and relationships which constitute our current understanding of the effects of head injury upon psychological functioning in children.

Personality or psychiatric disorders following head injury are typically manifest, albeit at different rates in different samples, as nervousness, bad temper and poor self-control. The severity and location of trauma have not been successfully used as predictors of subsequent disturbance, however, pre-traumatic factors have proven to be relevant.

Severe head injury has been associated with impairment of intellectual performance. Some authors (Flach & Malmros, 1972; Richardson, 1963) have found this deficit typified by a moderate deficit in I.Q., and a wide dispersion of sub-test scores. Although post-traumatic I.Q. has been negatively related to coma duration (e.g. Schaffer et al, 1973; Brink et al, 1970), severe deficits have also followed relatively brief (3-4 day) coma (Heiskanen & Kaste, 1974).

Severity of injury, as measured by post-traumatic coma, has been shown to be related positively to the extent and persistence of cognitive deficit (Levin & Eisenberg, 1979; Smith, 1961) to social maladjustment (Pazzaglia et al, 1975) and personality, physical and psychological disabilities in general (Stover & Zeiger, 1976). However, other researchers (Carlsson et al, 1968; Hjern & Nylander, 1962) have found coma duration unrelated to the late prognosis of severe head injury.

Use of the Glasgow Coma Scale has allowed a further understanding of the relationship between altered consciousness and subsequent handicap. Studies of prognosis indicate children receiving Glasgow Coma Scores at hospital admission of less than four points (of a possible 14) have, in virtually all cases, shown poor outcome or died, while those receiving five or greater on the scale have improved to varying degrees.

Other research (Levin & Eisenberg, 1979) has shown that memory and visuospatial deficits are positively related to Glasgow severity ratings, but that neuropsychological deficits may also occur in patients sustaining brief or no loss of consciousness.

Various memory deficits have been reported in studies of paediatric head injury at both long and short intervals after injury (Flach & Malmros, 1972; Klonoff & Paris, 1974; Levin & Eisenberg, 1979; Richardson, 1963). Problems with verbal memory and continuous recognition memory have been positively related to Glasgow severity scores.

Academic and behavioural difficulties are known sequels to paediatric head trauma (e.g. Brink et al, 1970; Flach & Malmros, 1972; Klonoff & Paris, 1974; Richardson, 1963). Different rates of deficit reported across studies have been attributed to difference in coma severity scores across samples, with more severe coma associated with more severe deficits.

PURPOSE OF THE PRESENT STUDY

This study is intended to investigate the effects of head injury upon neuropsychological and behavioural functioning in children. Three distinct groups of children

having sustained head injuries of varying degrees of neurologic severity are compared in order that the relationship between neurologic and psychologic parameters of head injury may be better understood. Research efforts to date have not been numerous, and extant studies have failed to use extensive neuropsychological assessments in conjunction with accepted neurologic measures.

Research efforts until the present have typically involved narrowly-defined samples of children (e.g. only severe head injury, or only mild head injury). This study is designed to retrospectively compare mildly, moderately, and severely head-injured patients on an extensive, standardized battery of outcome measures. In addition, within-group analysis is undertaken in order to provide information regarding the process of recovery from head injury and its relation to the severity of injury.

STATEMENT OF HYPOTHESES:

Hypothesis I

It is hypothesized that groups of head-injured children with mild, moderate and severe head injuries defined according to composite ratings of neurologic severity will

differ on frequency and extent of psychological and behavioural deficits. It is expected that severely head-injured children will have greater deficits than moderately head-injured children, and that the moderate group will have greater deficits than the mild group.

Hypothesis II

It is hypothesized that groups formed according to scores on a summary measure of neuropsychological dysfunction (Deficit Index) will differ in the frequency of neurologic abnormality on computerized axial tomography (CAT) scans, electroencephalograms (EEGs), and angiograms.

Hypothesis III

It is hypothesized that head-injured children who undergo intracranial pressure monitoring as a part of the neurosurgical treatment post-trauma, and whose intracranial pressure is maintained between 20-50 mmHg will have greater neuropsychological deficits and behavioural disturbances than those patients for whom intracranial pressure is maintained below 20 mmHg.

Hypothesis IV

It is hypothesized that the extent of alteration of consciousness at the time of hospital admission, as measured by the Glasgow Coma Scale, will be correlated with the extent of neuropsychological and behavioural disorders. Lower Glasgow scores are expected to correspond to increased impairment.

Hypothesis V

It is hypothesized that the duration of altered consciousness post-trauma, as defined by less than full score on the Glasgow Coma Scale, will be positively correlated with neuropsychological deficits and behavioural disorders.

Hypothesis VI

It is hypothesized that there exists a differential rate of recovery of neuropsychological functioning among head injury groups defined according to neurologic criteria. Severely head-injured children are expected to show slower, less extensive recovery.

Hypothesis VII

It is hypothesized that distinct patterns of

neuropsychological deficits will emerge for the three head injury groups defined according to neurologic criteria. A profile similarity coefficient (Cohen's r) is expected to indicate greater similarities between the average test patterns for the mild and moderate, and the moderate and severe groups, than between the mild and severe groups.

METHOD

SUBJECTS

All subjects were children who received treatment for head injuries at the Children's Hospital of Eastern Ontario (CHEO), or who received treatment at another treatment facility and were transferred to CHEO for evaluation or treatment. All patients regardless of the location at which they were medically treated, underwent a full neuropsychological assessment at the CHEO.

A total of 51 children were included in this research. Seventeen were classified neurologically as having sustained severe head injuries, 17 sustained moderate head injuries and 17 had neurologically mild injuries.

The 17 patients in the severe head injury group were all those children whose treatment subsequent to head injury consisted of continuous intracranial pressure (ICP) monitoring with the related neurosurgical maintenance procedures (described below). Ten of these patients had ICP maintained below 20 mmHg and another seven patients had ICP maintained between 20 and 50 mmHg. Decisions to monitor ICP are dependent upon the findings of neurological and neuroradiological examination and upon Glasgow Coma

Scores (Teasdale & Jennett, 1974) of seven points or less.

For each patient in the severe head injury group, one moderately and one mildly head-injured patient was selected.

These patients were matched for sex and were matched for age at the time of injury and at the time of testing as closely as is possible given the retrospective nature of this study.

The initial sample of head-injured patients consisted of 17 severely injured, 23 moderately injured and 47 mildly injured children. Eleven patients, one moderately injured and 10 mildly injured, were excluded from consideration because of premorbid histories involving: Evidence of more than one head injury, previous psychiatric treatment, hyperactivity with psychologic referral, speech problems with suspected epileptiform EEG activity, school failure with reading disability, inappropriate activity level in combination with behavioural or learning difficulties.

Because of the retrospective nature of this research, premorbid information was lacking for a number of patients. It is arguable however, that most of the patients with severe problems prior to injury have been identified through examination of transcripts from parental interviews conducted at the time of initial psychological testing. It is noteworthy that parent's subjective comments regarding their child's being "very active" etcetera were not sufficient to exclude the child from this research. If a child's behaviour

yielded definite consequences, ie. school failure, or if treatment was required, this was sufficient evidence to exclude the child. One male sustaining moderate injury was retained despite evidence of possible hyperactivity prior to injury because no other moderately injured patient could be matched for age at testing to the severely-injured cohort.

The overall ratio of males to females in this study was 10:7, with 30 males and 21 females included. This ratio reflects the greater incidence of head injuries among male children. The three severity groups were balanced for sex.

The ages of patients included in this research ranged from 2.5 to 17.3 years at the time of injury. Average ages at testing ranged from 4.7 to 17.6 with a mean of 10.5. Mean ages and injury-test intervals for the three severity groups are shown in Table 1.

TEST ADMINISTRATION AND NEUROLOGIC PROCEDURES

Neuropsychological assessments were completed in all cases by trained psychometricians at the Children's Hospital of Eastern Ontario (CHEO). Standardized test administration procedures were followed, as prescribed in the Knights-Norwood Neuropsychological Test Administration Manual (Knights & Norwood, 1975). Descriptions of the test

TABLE 1

MEAN AGES AND INJURY-TEST INTERVALS FOR MILD,
MODERATE AND SEVERE GROUPS.

MEAN AGE	MILD	MOD	SEV	OVERALL
AT INJURY	09.4	09.5	09.6	09.5
AT TESTING	10.4	10.4	10.7	10.5
I.T.I.	01.0	00.9	01.1	01.0

The groups did not differ significantly
on ages or injury-test intervals.

materials and scoring procedures are also explicitly presented in this manual. All assessments were conducted as part of the CHEO's regular referral process.

Measures of acute neurologic status were condensed by the author from detailed reports of attending neurosurgeons, and in some instances neurologists, laboratory technicians, nurses, and health care workers (e.g. speech pathologists and rehabilitation workers). A list of neurological measures considered in this research is presented in Table 2.

Levels of consciousness were rated by the author according to the Glasgow Coma Scale criteria as applied to Emergency Department reports of responsiveness at the time of admission. Although criteria for scoring of this coma scale are explicitly presented in the literature, (Teasdale & Jennett, 1974), and inter-rater reliability among even inexperienced hospital personnel is high, the author's ratings with the scale were compared to those made by a staff psychometrician. Agreement for 40 cases blindly rated, exceeded 90 per cent. Raw intracranial pressure values were extracted, in the majority of cases, from hourly reports of the digital display on the Ladd ICP monitor. CAT scans of the cranium, and bilateral carotid angiograms were rated as being normal or abnormal according to the accompanying clinical reports. The nature and location of abnormalities was also taken from these reports.

TABLE 2

NEUROLOGIC MEASURES EMPLOYED

DURATION HOSPITALIZATION

number of days

SEIZURES

presence or absence of post-traumatic seizures

OVERALL NEUROLOGIC SEVERITY RATING

mild:

no loss of consciousness (LOC)
LOC less than 20 mins.
linear fracture without LOC

moderate

LOC greater than 20 mins.
skull fracture with contusion
with neurologic findings
with haemorrhage
with CT Scan findings
with focal EEG or
sustained diffuse abnormality
contusion with CT Scan findings

severe:

Glasgow Coma Score less than 7
with Intracranial Pressure
monitoring

EEG MEASURES

normal or abnormal;
location of abnormality (diffuse
vs. focal; hemisphere; lobe)

severity of abnormality: mild
intermittent, mild, mild/moderate,
moderate, moderate/severe, severe,
paroxysmal, epileptiform.)

CAT SCAN MEASURES

normal or abnormal,

TABLE 2 continued

	location of abnormality (diffuse vs. focal; hemisphere; lobe.)
ANGIOGRAM MEASURES	same as for Cat Scan
GLASGOW COMA SCALE SCORE	coma at hospital admission assessed retrospectively (see Appendix 1)
DURATION OF NOT BEING FULLY CONSCIOUS	days to recovery of motor and eye-opening responsiveness
DURATION OF NOT BEING FULLY CONSCIOUS (including speech functions)	days to recovery of verbal, motor, and eye-opening responsiveness
CAUSE OF HEAD INJURY	1) pedestrian in motor vehicle accident (MVA) 2) bicycling in MVA 3) vehicle passenger in MVA 4) fall 5) other
INTRACRANIAL PRESSURE MEASURES	1) actual highest ICP value taken from hourly ICP records 2) ICP group: i) pressure maintained below 20 mmHg; ii) pressure above 20 mmHg for more than half the hourly readings for one day. 3) actual daily averages for ICP

The interpretation of EEG records was conducted in all cases by a neurologist on staff at CHEO with specialty in paediatric electroencephalography. Although the EEG records were in some cases initially interpreted by other neurologists, these were re-rated for this research by the participating neurologist.

Parents' ratings, where available, were completed at the time of neuropsychological testing. Also, transcripts from clinical interviews with parents were available to the author, and were useful in screening pre-morbidly abnormal children from the study.

The patients' ages at the time of injury and at testing were taken from official medical records as were dates used in determining duration of hospitalization and relevance of clinical reports (information gathered subsequent to neuropsychological testing was not considered relevant).

NEUROSURGICAL MAINTENANCE AND ICP MONITORING

There currently exist no methods for treating the primary mechanical effects of traumatic head injury (Bruce et al., 1979). Medical maintenance is therefore aimed at preventing or reversing the deleterious secondary effects of brain insult, and at optimizing the conditions for early

repair in the brain.

Elevated intracranial pressure (ICP) is associated with poor prognosis in cases of head injury (Toupp, 1967; Vapalahti & Toupp, 1971) and the continuous monitoring of ICP has proven to be extremely valuable in the management of patients in coma following severe head trauma. The aggressive management of intracranial hypertension is now an established procedure in the neurosurgical maintenance of severe head trauma at the CHEO. The management regime involves these treatments and procedures:

Upon arrival at hospital, the patient undergoes endotracheal intubation and is placed on artificial respiration with hyperventilation as one of the measures to control ICP. A computerized tomography (CT) scan or cerebral angiography is next conducted in order to examine for mass lesions. If such operable lesions are ruled out, an ICP sensor is inserted through a burr hole made in the left or right frontal area of the cranium. The sensor is a fiberoptic pressure transducer placed between the dura and the cranium, which has a pressure sensitive membrane placed against the dura. The mechanisms of this sensor and the technical advantages associated with its use have been described thoroughly (Ivan, Choo & Ventureyra, 1981).

The drug Decadron is administered intravenously to prevent or treat brain oedema, while increased ICP is treated

by osmotherapy (administration of the drug Mannitol). A barbiturate, Pentothal, is administered to protect the ischaemic brain. This drug drastically reduces the cerebral metabolic requirement for oxygen, thereby reducing the intracranial blood flow and ICP. Where required, a deep barbiturate coma with "burst suppression" or, in more severe cases, flat EEG, is induced to control elevated ICP.

To summarize, the goal of therapy is to reduce brain bulk and ICP, and, to control and reversibly suppress brain activity and metabolic functioning. The use of barbiturate coma with artificial respiration places the damaged brain in a slowed or resting state allowing more adequate recovery of brain functioning upon cessation of the therapy (Ivan et al., 1981).

TEST MATERIALS

The neuropsychological assessment procedures to be included in this research were selected from the standard battery, developed by R. Knights, which is in use at the CHEO (Knights & Norwood, 1979).

A number of the tests in the Knights battery have been derived from the Halstead Neuropsychological Test Battery for Children and Allied Procedures, and from the Reitan-Indiana

Neuropsychological Test Battery and Allied Procedures. A number of these tests have been employed previously in studies of outcome following head injury in children (Klonoff et al., 1977; Klonoff & Paris, 1974; Klonoff et al., 1969; Levin & Eisenberg, 1979). The validity and reliability of these tests for discriminating brain-damaged patients from non-brain-damaged patients have been described by Halstead (1947), Reitan (1955), and Vega and Parsons (1967). Tests of the ability of these batteries to lateralize and localize brain damage, and to discriminate the type and chronicity of pathology have been summarized by Boll (in press).

Specific neuropsychological tests employed are summarized below. Further details are available in standard texts of neuropsychology, for example Lezak (1976).

Wechsler Intelligence Scale for Children - Revised (WISC-R)

The Wechsler I.Q. test is a very widely used measure of children's intellectual abilities. The test is composed of 12 subtests, of which 10 are used to yield two subscores and a total score. The two subscores are Verbal and Performance scores.

Peabody Picture Vocabulary Test - I.Q. (PPVT IQ)

The PPVT IQ is a measure of receptive language ability. The examiner presents a stimulus word either verbally

(hearing vocabulary) or on a printed card (reading vocabulary). The child responds by selecting the corresponding picture from among four pictures presented on a response card. M.A. and I.Q. scores are derived. The I.Q. scores are employed in this research.

Wide Range Achievement Test (WRAT)

This is a test of three academic skills : Reading, Spelling, and Arithmetic. The skills are measured from the pre-school level to the college level, yielding raw scores that may be converted to school grades, standard scores, or percentiles. Standard scores are used in this research.

Category Test (CAT)

This is a test of abstract reasoning ability. Stimuli, which are presented via a slide projector, vary in size, shape, number, location, color and intensity. The child's task is to extract a principle from each of five subtests. The sixth subtest consists of previously presented slides, and is a memory measure.

Tactual Performance Test (TPT)

This is a test of psychomotor skills. The test involves tactual and kinesthetic perception ; a formboard is placed before the blind-folded child who is required to put a number

of differently shaped blocks into their designated spots, with the preferred hand, non-preferred hand, and then with both hands. After removal of the blind-fold the child is required to draw a picture of the board (which has not been seen) complete with the blocks in their places. The times required for the three trials are summed to yield a total score. The number of blocks correctly drawn in the picture provides a Memory score, and the Location score tells the number of blocks correctly placed in the drawing.

Finger Agnosia Examination (FGAG)

The child's fingers are tapped lightly by the examiner in a standard location, in a standard pattern. The preferred hand is stimulated first, then the non-preferred hand. Errors in perception are recorded.

Finger Tapping (TAP)

The child depresses a tapping key equipped with a counter, first with the dominant hand, then with the non-dominant hand. The score for each hand is the average of the best three out of four 10 second trials (within five points) for that hand.

Aphasia Screening Test and Right-Left Orientation (TOTAPHAS & RL ORIENT)

This is the most widely used of the aphasia tests. It is a brief test which measures expressive, receptive, and verbat-symbolic language abilities, both verbal and written. LR ORIENT and body orientation are also evaluated in this test. The body orientation score is not considered in this research.

Pegboard Test (PB)

In this test the child is required to rapidly place "keyhole shaped" pegs into five matching columns of holes in a wooden board. Scores for the dominant hand and the non-dominant hand are the number of seconds required to complete the task.

Errors are recorded each time a peg is dropped, but this score is not considered in this research.

Sentence Memory Test (SENMEM)

This is a test of immediate auditory memory. Twenty-five sentences of increasing difficulty are presented orally (from a tape recording). The child's task is simply to repeat each sentence. The score is the number of sentences correctly repeated.

Verbal Fluency Test (FLUNCY)

As the name suggests, this is a test of verbal fluency.

In two 60 second trials, the child is required to produce as many words as possible beginning with the sound "p", and then with the sound "c". The child's score is the average of the number of words produced for the two trials.

Target Test (TARGET)

This test provides a measure of visuospatial skills, and visual memory. The test administrator taps a pattern on a sheet containing nine black dots. Then, following a three second delay, the child is required to draw the pattern on a test sheet. The score is the number of correctly drawn patterns of the 20 presented.

Trails Test (TRAILTOT)

This is a test of visuomotor and sequencing skills. The test is administered in two parts : in part A the child draws a line joining 15 consecutively numbered circles as fast as possible. In part B, the child connects a number of circles again, however, now the circles contain numbers and letters, and the child is required to alternate between the numbers and letters (eg. 1, A, 2, B, etc.). The score is the time required to complete both trials.

Conners' Parents' Questionnaire (CONNERS)

The CONNERS scales consist of 93 questions, tapping

eight factors of adjustment: conduct problem, anxiety, impulsive-hyperactive, learning problem, psychosomatic, perfectionism, anti-social, and muscular tension. The CONNERS scales are widely used both in psychological research and in clinical practice, and reliability and normative data are available (Trites, 1979).

Deficit Index (DI)

This is a summary measure of the level of a child's performance relative to that of the normative sample.

It does not take into account the pattern of performance but only describes the percentage of test scores below two standard deviations below the mean.

Standardized Scores

All the raw scores attained by the head-injured children in this study were converted into T-score form (mean=50, SD=10). All statistical analyses were conducted upon the T-score ("standardized score") data. The reason for this conversion of scores is to provide some consistency for the levels of performance between the various chronological age groups considered (Knights, 1973).

Neuropsychological Test Profiles and Profile Comparisons

A neuropsychological profile is a set of scores whose pattern describes the performance of an individual or group on a number of neuropsychological tests. The use of computerized test profile comparisons (Knights, 1973; Knights & Watson, 1968) allows the matching of each subject's test scores with those of all the other head-injured children included. This automated procedure employs Cohen's (1969) coefficient of profile similarity, and allows the evaluation of the similarity between a child's profile and the profiles of other children assessed, or of the similarity between average profiles created from the average test scores for groups of children. The profile matching technique is sensitive to not only levels of performance, but also patterns of abilities and deficits, and therefore gives an added dimension to inter-patient comparisons.

STATISTICAL ANALYSES

Standardized batteries of neuropsychological tests are lengthy, typically involving in excess of 100 subtests. This is the case with the battery employed here. However, 13 tests yielding 24 sub-scores were selected from the battery -- these tests, listed in Table 3, are considered to be representative of major neuropsychological functions. Scores

TABLE 3

PSYCHOLOGICAL TESTS WITH ABBREVIATED TEST NAMES AND NAMES OF FUNCTIONS OR SKILLS MEASURED

INTELLIGENCE MEASURES

WISCR-V	Wechsler Intelligence Scale For Children Revised Verbal Score
WISCR-P	Performance score
WISCR-F	Full scale score

RECEPTIVE LANGUAGE FUNCTION

PBY IQ	Peabody Picture Vocabulary Test, Intelligence Quotient
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ACADEMIC ACHIEVEMENT

WRAT R	Wide Range Achievement Test, reading score
WRAT S	spelling score
WRAT A	arithmetic score

ABSTRACT REASONING

CAT T	Category Test, total score
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PSYCHOMOTOR SKILLS

TPT T	Tactual Performance Test, total score
TPT MEMORY	Memory score
TPT LOCATN	Location score

MOTOR SPEED MEASURE

TAP T	Tapping Test, total score
TAP DH	Dominant hand score
TAP NDH	Non-dominant hand score

SENSORY-PERCEPTUAL FUNCTION

FGAG R	Finger Agnosia Test, right hand
FGAG L	left hand

MOTOR SPEED - EYE-HAND COORDINATION

PB TMD	Pegboard Test, dominant hand time score
PB TMN	non-dominant hand time score

TABLE 3 continued

LANGUAGE FUNCTION

TOT AP Aphasia Screening Battery, total score
RL ORIENT right-left orientation subscore
 of Aphasia Screening Battery

AUDITORY MEMORY

SENMEM Sentence Memory Test

VERBAL FLUENCY

FLUNCY Fluency Test

VISUOSPATIAL AND VISUOMEMORY FUNCTION

TARGET Target Test

VISUOMOTOR AND SEQUENCING SKILLS

TRAILTOT Trails Test, total score

BEHAVIOUR RATING SCALES

CONNERS 1-8 Connors Parents Questionnaire
 1)conduct problem 2)anxiety 3)impulsive-
 hyperactive 4)learning problem 5)psychosomatic
 6)perfectionism 7)anti-social 8)muscular
 tension

DEFICIT INDEX a summary measure of psychological
 dysfunction which indicates the percentage
 of scores more than 2 SDs below the mean
 Ranges= < 9.9; normal
 10-19.9 mildly abnormal
 20-29.9 moderately abnormal
 30 & up severely abnormal

for all the tests have been "standardized" (via t transformations) to have a mean of 50, and a standard deviation of 10. This is done in order to facilitate comparability among children of different ages. (Knights, 1973.)

Several methods were employed in the analyses of results. These are listed below:

- 1) ANOVAs comparing the three severity groups on all 24 neuropsychological sub-scores and on the eight behavioural ratings.
- 2) ANOVAs comparing the two deficit index groups on 10 neurological sub-scores.
- 3) Chi Square analyses examining the relationship between severity rating (three groups) and the frequency of deficit on 24 neuropsychological sub-scores.
- 4) Correlations between ICP measures and neuropsychological sub-scores.
- 5) Correlations between Glasgow Coma Scale score (see Appendix 1) and the 24 neuropsychological sub-scores.
- 6) Correlations between the duration of altered consciousness and the 24 neuropsychological sub-scores plus eight behavioural scores.
- 7) One-way ANOVAs with repeated measures, comparing the two severity groups (mild/moderate and severe) on eight psychological test scores.

8) Cohen's profile similarity coefficient for the three head-injury groups defined according to neurological severity ratings.

9) Cohen's r for the ten best matches for each group profile.

RESULTS

Analyses of Variance

Relation of Neurologic Severity Ratings to Psychological Test Scores

In order to compare performances on psychological tests across severity groups, One-Way Analyses of Variance (ANOVAS) were performed with the three levels of neurologic severity rating as the independent variable, and with individual normalized test scores as dependent variables. Thirteen tests, yielding 24 scores were selected prior to data analyses for inclusion in this analysis (See Table 3). Means and standard deviations for all the variables are listed in Appendix 2. Of the 24 subscores considered, significant group differences were found on seven subscores.

Findings indicate that a significant difference among groups exists for the Performance score of the WISC ($F=3.77$; $df=2,44$; $p=.030$). Multiple comparison tests (Newman-Keuls, $\alpha=.05$) revealed that all the differences among groups were significant with the mild, moderate and severe groups receiving the highest, intermediate and lowest

scores respectively. Group differences on the WISC-R Verbal and Full-scale scores did not reach significance. These results are represented graphically in Figure 1.

Other test scores which differed significantly among severity groups were the Tactual Performance Test (TPT) total score ($F=3.43; df=2,40; p=.042$) and the three scores on the Tapping Test (TAP): TAP dominant hand score ($F=7.67; df=2,48; p=.000$), TAP non-dominant hand score ($F=13.00; df=2,48; p=.000$), TAP total score ($F=13.37; df=2,44; p=.000$). The TPT is a measure of psychomotor skills involving kinesthetic and tactual perception, and the TAP measures motor speed. For each of the above sub-tests, multiple comparisons (Newman-Keuls, $\alpha=.05$) revealed that scores for the mild and moderate groups were significantly greater than those of the severe group. Also, the TAP score for the non-dominant hand was significantly higher in the moderate group than in the mild.

A significant difference among severity groups also occurred on the Pegboard Test (PB) time score for the dominant hand ($F=3.39; df=2,48; p=.042$). On this subtest, the mild and moderate groups showed greater speed and accuracy in dominant hand coordination.

The final significant group differences emerged on the test of verbal Fluency (FLUNCY) ($F=3.26; df=2,47; p=.047$). Newman-Keuls comparisons indicated all group differences were

Figure 1. Average I.Q.s for three severity groups

significant. The ordering of groups from least to most impaired is moderate, mild, severe.

Among the Parents' behavioural rating scales, only the sixth scale (perfectionism) was significantly related to neurologic severity of injury ($F=5.92; df=2,37; p=.006$). The moderate group received higher scores than the severe group, indicating that the moderately head-injured were more perfectionistic (Newman-Keuls, $\alpha=.05$). All other scales failed to reach significance.

Comparison of Psychological Test Scores Between ICP Groups
(pressure maintained below 20 millimeters of mercury (mmHg),
or, above 20 mmHg)

One-Way Analyses of Variance (ANOVAS) were conducted with the two levels of intracranial pressure (ICP) as the independent variable and individual psychological test scores as dependent variables. Twenty-four analyses were conducted (tests listed in Table 3). The group means and standard deviations for all the tests are presented in Appendix 3.

No significant differences were found among any of the groups on any of the tests.

Chi Square Analyses

Relation of Deficit Index (DI) to Neurological Variables

A definition of deficit index is provided in Table 3, and the neurological measures included are listed in Table 2.

Chi Square analyses were conducted to compare the frequency of occurrence of neurologic deficits across deficit index groups. Ten Chi Square analyses were conducted (those variables not analysed due to sample size limitations are listed below). Four of the analyses reached significance.

Deficit index scores were significantly related to Glasgow Coma Scale ratings (Chi Sq.=12.34;df=3;p=.006). Eighty-nine per cent of those children with deficit indices greater than 30 received Glasgow ratings below 8, and 77 per cent with deficit indices in the normal range received Glasgow scores exceeding 8. Also, 63 per cent with Glasgow scores over 8 had normal deficit index scores.

Overall neurologic severity ratings also correspond to deficit index ratings (Chi Sq.=14.15;df=6;p=.028). Fifty per cent of those with DIs in the normal range sustained mild injuries, whereas 67 per cent with DIs indicating severe deficit sustained severe injuries. Sixty-five per cent of all patients with mild injuries had DIs in the normal range.

DI scores were also related to the presence of abnormality in CAT Scan findings (Chi Sq.=12.02;df=3;p=.007), with 81 per cent of children having normal DIs showing normal

CAT Scans as well. Conversely, 80 and 86 per cent of those with moderate and severe DI deficits showed CAT Scan abnormalities. Sixty-eight per cent of all patients with normal CAT Scans had DIs in the normal range.

The relation between EEG abnormality and DI approached significance ($\chi^2 = 7.41$; $df = 3$; $p = .059$) with an average of 88 per cent of patients with moderate and severe DIs showing EEG abnormality.

The frequency of neurologic deficit was unrelated to DI for the following measures: presence of seizure, nature and severity of EEG abnormality, nature of CAT Scan findings (focal vs. diffuse), cause of injury, and presence of angiogram abnormality. Because of limitations of sample sizes, no analyses were conducted for these variables: nature (focal vs. diffuse) of angiogram abnormality, and location (hemisphere and lobe) of EEG, CAT Scan, and angiogram abnormalities.

Relation of Neurological Severity Ratings to Frequency of Psychological Test Score Deficits

Psychological tests considered are listed in Table 3, and the criteria for neurological severity rating are presented in Table 2.

The Chi Square statistic was employed in order to examine differences in the rates of occurrence of psychological deficits across severity groups. Deficits were defined as all scores falling below two standard deviations below the mean (means are determined from normative data). Results are presented in Table 4.

Correlational Analyses

Relation of Intracranial Pressure (ICP) Measures with Psychological Test Scores

The relationship between ICP measures and psychological test scores was examined through Pearson correlation coefficients. The measures of ICP employed were (a) overall average ICP value for all days monitored, (b) actual peak ICP value selected from daily average values, (c) ICP daily

TABLE 4

SIGNIFICANT RELATIONSHIPS BETWEEN NEURO-SEVERITY RATINGS AND
PSYCHOLOGICAL TEST SCORES.

TEST NAME*	CHI SQ.**	SIGNIF	PER CENT SHOWING DEFICIT		
			MILD	MODERATE	SEVERE
WISCR-FS	07.85	.019	12(2)	12(2)	47(8)
WISCR-P	05.80	.055	12(2)	12(2)	41(7)
PBY IQ	07.71	.021	41(7)	6(1)	12(2)
WRAT R	06.53	.038	53(9)	12(2)	35(6)
TPT T	11.02	.004	18(3)	29(5)	71(12)
TPT MEM	05.78	.056	06(1)	29(5)	41(7)
TPT LOCAT	06.21	.045	18(3)	35(6)	59(10)
TAP T	17.65	.000	06(1)	06(1)	59(10)
TAP DH	07.93	.019	06(1)	00(0)	29(5)
TAP NDH	15.38	.000	06(1)	00(0)	47(8)
PB TMD	09.97	.007	06(1)	12(2)	47(8)
TARGET	07.71	.021	12(2)	10(1)	41(7)
DI	14.15	.028	06(1)	12(2)	35(6)

bracketed values are frequencies.

*full test names listed in Table 3.

**df for each chi sq.=2.

average values for day 1 and (d) day 2.

The psychological tests were those indicated in Table 3.

Of all the correlation coefficients computed, only three were significant: Scores on the Verbal Fluency Test (FLUNCY) correlated with overall average ICP ($r=.445, p=.048$) and actual peak ICP value ($r=.438, p=.051$). Peak ICP value also correlated with the Wide Range Achievement Test (WRAT) spelling score ($r=.631, p=.025$). All remaining correlations were insignificant.

Relation of Glasgow Coma Scores with Psychological Test Scores

Pearson Product Moment Correlations were conducted in order to measure the relationships between Glasgow Coma Scale scores and normalized scores on selected psychological tests. These analyses were conducted for all patients, irrespective of group membership. Results of the analyses are presented in Table 5.

The findings indicate that post-traumatic intelligence as measured by the WISC-R is related to severity of coma at the time of hospitalization. The Verbal and Performance subscores, and the Full Scale score were positively correlated to Glasgow scores, indicating that those in

TABLE 5

GLASGOW COMA SCALE CORRELATIONS WITH SCORES ON PSYCHOLOGICAL TESTS

TEST	CORR	SIGNIF
WISCR-V	.274	*
WISCR-P	.438	***
WISCR-F	.391	**(p=.004)
PBY IQ	.017	N.S.
WRAT R	.160	N.S.
WRAT S	.181	N.S.
WRAT A	.133	N.S.
CAT T	.319	*
TPT MEMORY	.378	**
TPT LOCATN	.284	*
TPT TOT	.270	*
FGAG R	.140	N.S.
FGAG L	.254	*
TAP DH	.408	**(p=.002)
TAP NDH	.483	***
TAP T	.504	***
PB TMD	.358	**
PB TMN	.099	N.S.
TOT AP	.363	**
R-L ORIENT	.161	N.S.
SENMEM	-.149	N.S.
FLUNCY	.234	*
TARGET	.205	N.S.
TRAILTOT	.315	*

* =signif.05

** =signif.01

*** =signif.001

For explanation of abbreviations of test names,
see Table 3.

"deeper" coma typically displayed lower intelligence scores, particularly Performance scores.

Patients with more severe comas also generally achieved lower scores on certain measures of abstract reasoning (Category test), language ability (total Aphasia score, and verbal Fluency test), sensory function (Finger Agnosia score for the left hand), and psychomotor ability (Tactual Performance Test), motor steadiness and speed (Pegboard test, and all Tapping test scores), and visual-motor sequencing skills (Trails test total score). It is noteworthy that the highest correlations (excluding those for IQ scores) emerged for the three measures of motor speed provided by the Tapping Test scores.

Correlational analyses for the Glasgow scale with the Connors Parents' Rating Scales disclosed no significant relationships. These coefficients are presented in Appendix 4.

Relation of Duration of Unconsciousness with Psychological Test Scores

The correlations between the duration of unconsciousness (a) including speech functioning, and (b) excluding speech functioning, are presented in table form in Table 6.

TABLE 6

DURATION OF UNCONSCIOUSNESS (1=not including speech;
2=including speech) CORRELATED WITH PSYCHOLOGICAL TEST SCORES

TEST	UNCONSCIOUS1		UNCONSCIOUS2	
WISCR-V	-.170	N.S.	-.197	N.S.
WISCR-P	-.379	** (p=.004)	-.438	***
WISCR-F	-.304	*	-.350	**
PBY IQ	-.073	N.S.	-.038	N.S.
WRAT R	-.021	N.S.	-.056	N.S.
WRAT S	-.062	N.S.	-.167	N.S.
WRAT A	-.041	N.S.	-.073	N.S.
CAT T	-.316	*(p=.014)	-.337	*(p=.011)
TPT MEMORY	-.261	*	-.310	*
TPT LOCAT	-.284	*	-.281	*
TPT T	-.469	***	-.447	***
FGAG R	-.179	N.S.	-.150	N.S.
FGAG L	-.250	*	-.251	*
TAP DH	-.539	***	-.666	***
TAP NDH	-.596	***	-.671	***
TAP T	-.664	***	-.708	***
RL ORIENT	-.053	N.S.	-.062	N.S.
TOTAPHAS	-.318	*(p=.014)	-.354	**
PB TMD	-.599	***	-.575	***
PB TMN	-.289	*	-.183	N.S.
SEMEM	-.013	N.S.	-.002	N.S.
FLUNCY	-.221	N.S.	-.277	*
TARGET	-.239	*	-.275	*
TRAILTOT	-.166	N.S.	-.222	N.S.
CONNERS1	-.259	N.S. (p=.054)	-.275	*
CONNERS2	-.269	*	-.301	*
CONNERS3	-.182	N.S.	-.217	N.S.
CONNERS4	-.349	*(p=.014)	-.303	*
CONNERS5	-.152	N.S.	-.213	N.S.
CONNERS6	-.309	*	-.337	*
CONNERS7	-.090	N.S.	-.098	N.S.
CONNERS8	-.176	N.S.	-.189	N.S.

* =signif.05

** =signif.01

*** =signif.001

For explanation of abbreviations of test names,
see Table 3.

Changes in Psychological Scores Over Time

Several One-Way ANOVAS with repeated measures on psychological test scores were conducted to compare the post-traumatic rate of change in test scores across severity groups.

Because psychological re-testing was not common in the moderate and particularly the mild group, and because these groups generally did not differ in previous analyses, these two groups were combined for comparison with the severe group. The mild/moderate and severe groups consisted of six patients each. Two sets of test scores were considered for each patient--the first falling within the first half year post-trauma, the second within one and a half years of injury. The ages and injury-test intervals (ITIs) are presented in Table 7:

TABLE 7

GROUP	AGE INJURY	TEST(ITI AVG.)	RE-TEST(ITI AVG.)
mild/mod.	10.85	.33 yrs.	.90 yrs.
severe	12.30	.25 yrs.	1.27 yrs.

Of the tests generally employed in this research, the

following were suitable for repeated measures analyses i.e., were re-administered to three or more subjects in each group within the ITI ranges described above: WISC-R, CAT T, TAP T, FGAG, APHASIA, SENMEM, RL DISC, PB TMD. Means and standard deviations are presented in Appendix 5.

Scores on the WISC-R Performance scale showed significant improvement across the two testings ($F=6.83; df=1,8; p=.053$). The severe group had significantly lower scores ($F=6.83; df=1,8; p=.031$) however, there was no interaction between group membership and rate of recovery.

On the Aphasia test total score, a measure of language function, the interaction between group membership and recovery was significant ($F=5.57; df=1,10; p=.037$) with the severe group showing an average improvement slightly in excess of 10 points, and the mild/moderate group showing essentially normal performance at both testings.

Scores for the severe group were inferior to those for the other group on the TAP T ($F=43.28; df=1,7; p=.000$), a measure of motor speed. Also, auditory memory (SENMEM) was poor for severely injured patients ($F=6.78; df=1,6; p=.040$). For both tests, score changes over time were insignificant as were the interactions.

Correlational Analyses

Pearson correlation coefficients were calculated to examine the relationship between injury-test interval (defined in months) and psychological test scores for all patients, irrespective of group membership.

None of the correlations reached significance. The coefficients are presented in Appendix 6.

Relations Among Neurologic Indices

Chi square and correlational analyses were employed to examine the relations among selected neurologic indices of head injury.

Overall neurologic severity ratings were related to presence or absence of abnormality in EEG (Chi sq.=8.03;df=2;p=.018) and Cat Scan (Chi sq.=12.57; df=2;p=.002). The percentage of children in each group showing deficit is presented in TABLE 8:

Measure	mild	moder.	severe
EEG	33	69	81
Cat Scan	00	50	79

Glasgow Coma Scale, scores below eight (relatively severe

coma) occurred in 100 per cent of patients with severe injuries, 35 per cent with moderate injuries, and did not occur in the mildly injured group ($\chi^2=34.37$; $df=2$; $p=.000$). High scores on the Glasgow scale were related to shorter hospitalization ($r=-.670$; $p=.001$), shorter periods of altered consciousness excluding speech functioning ($r=-.671$; $p=.001$) and including speech function ($r=-.756$; $p=.001$).

Patterns of Psychological Test Performance

Patterns of performance for the mild, moderate and severe head injury groups are plotted in Figures 2 and 3. For this analysis only, scores for the entire battery of tests described by Knights and Norwood (1979) are included, with the exception that the following tests are excluded because they were administered to less than 50 per cent of the total sample: MAZE, PBYRMA, PBYRIQ, BODORN, BOSTON, SPPEC, CON-CP, CON-IP, CON-TA, CON-HYP. The WRAT RG and WRAT SG were excluded because less than half of the mild group had scores on these measures. (Full test names for all the tests in the battery are presented in Appendix 7. Group means and standard deviations for the complete battery are presented in Appendix 8.)

FIGURE 2. Mild, Moderate and Severe Profiles
(full test names in Appendix 7)

These profiles are visual representations of the means of the normalized scores for each of the three severity groups on each of the selected psychological tests. They illustrate visually the performance of each group relative to the other groups and can therefore help isolate those tests which show uniform depression for all the head-injured children, and those which may be most useful in discriminating among groups.

Cohen's coefficient of profile similarity (Cohen, 1969) was applied to the three average profiles. The correlation between the severe profile and the moderate profile was .62, that between the severe and mild groups was .53, and that between the moderate and mild was .67. This indicates, as expected, that the patterns of deficits for the mild and severe groups are least similar. The mild pattern resembles the moderate to a greater extent than the moderate resembles the severe.

From among the 51 head-injured children included in this research, the ten having profiles most highly correlated with the average profiles for the mild, moderate and severe groups were selected. The statistic employed was, once again, Cohen's profile similarity coefficient. These relationships are summarized in Table 9.

The coefficients in Table 9 revealed that the profile for the severe group is matched primarily with children

TABLE 9

10 BEST MATCHES FOR THE AVERAGE PROFILES FOR THE MILD, MODERATE, AND SEVERE HEAD-INJURY GROUPS.

SEVERE GROUP

CHILD	COHEN'S r	NEURO-RATING
J.C.	.67	SEVERE
C.R.	.65	SEVERE
W.L.	.62	SEVERE
W.J.	.61	SEVERE
F.J.	.59	SEVERE
L.S.	.56	MODERATE
C.S.	.55	SEVERE
G.J.	.55	MILD
O.F.	.54	MODERATE
D.B.	.53	SEVERE

MODERATE GROUP

D.J.	.58	MODERATE
O.F.	.57	MODERATE
W.L.	.54	MODERATE
J.C.	.54	SEVERE
S.V.	.50	SEVERE
C.R.	.48	SEVERE
G.J.	.48	MODERATE
L.S.	.46	MODERATE
G.J.	.46	MILD
E.P.	.45	MILD

MILD GROUP

C.R.	.58	SEVERE
J.C.	.57	SEVERE
G.J.	.53	MILD
E.P.	.50	MILD
W.L.	.49	MODERATE
T.C.	.48	MILD
D.J.	.45	MODERATE
L.K.	.44	MODERATE
B.K.	.44	MODERATE
R.R.	.44	MILD

having suffered severe injuries. The number of such homogeneous matches and the magnitude of the correlations indicate the pattern of deficit in severe injury to be the most distinct among the three average patterns. The average mild profile is next distinctive, the moderate profile least distinctive.

DISCUSSION

The present research was undertaken in order to examine brain-behaviour relationships in the context of traumatic head injury occurring in children. Most fundamentally, this research has demonstrated that children, sustaining neurologically severe injuries show greater deficits on certain psychologic and behavioural measures than those sustaining moderate injuries, who in turn show greater deficits than the mildly injured.

The Relation of Intellectual Deficits to Severity of Injury

It is well known that severe cranio-cerebral trauma may cause general intellectual impairment (eg. Brink et al., 1970; Heiskanen & Kaste, 1974; Klonoff et al., 1969; 1977; Levin & Eisenberg, 1979; Richardson, 1963; Stover & Zeiger, 1976).

A phenomenon less clearly understood is the relationship between the severity of an injury and the nature and extent of the specific deficits resulting.

In the present study, it has been demonstrated that the Performance scale of the WISC-R is a useful measure in discriminating among groups of mildly, moderately, and severely head-injured children, whereas the Verbal and Full

Scale scores are not. The severe group showed Performance I.Q.s approximately 19 points below the age mean, with the moderate and mild groups attaining average scores only six and two points below the mean respectively.

The greater sensitivity of Performance I.Q. to the effects of head injury has been demonstrated with adults in longitudinal studies by Becker (1975) and Mandleberg and Brooks (1976) as well as with children (Chadwick et al., 1981).

However, the information yielded by these studies and the present study differs in a fundamental respect. The adult studies, and Chadwick's research with children, have compared single groups of head-injured children to matched controls. They have therefore related deficits on psychological tests, in this case Performance I.Q., to the occurrence of head injury. They did not attempt to further analyse the relation between the nature and severity of injury, and the extent of psychological deficit. The relative Verbal, Performance, and Full scale I.Q.s of mild, moderate, and severe head-injury groups have not been analysed in any previous research. Earlier studies, excluding that by Chadwick et al., have reported only Full scale I.Q.s (Brink et al., 1970; Flach and Malmros, 1972; Klonoff et al., 1969, 1977; Richardson, 1963) for homogeneous groups of patients defined according to some neurologic criterion. Richardson (1963) and Flach and Malmros (1972) have reported long-term deficits of 10-30

points in Wechsler I.Q. as long as 2-14 years after severe trauma. Klonoff's longitudinal research (1969, 1974, 1977) has revealed Full scale Wechsler I.Q. deficits for head-injured patients relative to normal controls. Within the head-injured group however, the severity of injury was not significantly related to I.Q. deficits (Klonoff et al., 1969).

Becker (1975) states that among head-injured adults, diffuse cerebral pathology, like that caused by blunt head injury, has greater effects upon non-verbal performance areas of the Wechsler I.Q.. The favoured explanation, which Becker cites, attributes the deficits on performance tasks to their dependence upon attention, concentration, immediate memory and present efficiency rather than general knowledge, verbal fluency, education, experience, and long-term memory. The generalizability of this explanation to the present paediatric population is dependent upon the differential rates and magnitudes of deficiencies on neuropsychological tests which are known to specifically tax these attributes and abilities. Discussion of this hypothesis is continued after a brief discussion of the results obtained on these tests.

The Relation of Neuropsychological Deficits to Severity of Injury

In addition to intellectual functioning the tests employed in this study measured language function, abstract reasoning, academic achievement, motor and psychomotor and visuomotor abilities, sensory-perceptual and visuospatial abilities and behavioural ratings.

Of all the tests which were considered in group comparisons, those which showed significant differences among groups were: the Tapping test, dominant hand score, nondominant hand score, and total score; the Pegboard score for the dominant hand; the Fluency test and the total score for the Tactual Performance Test. For all of the tests, excluding the Fluency and non-dominant Tapping measures, the moderately injured and mildly injured groups did not differ from each other but scored significantly higher than the the severely injured group. In the case of Fluency and non-dominant Tapping, the moderate, mild, and severe groups showed progressively poorer performance respectively.

While these measures of neuropsychological function are not the only ones which were related to neurological indices of the nature and severity of injury, they are the only ones upon which significant group differences emerged.

Scores on the three Tapping test scales indicate that fine motor speed is more greatly reduced following neurologically severe injuries than following mild or

moderate injuries. In addition, the nondominant hand score showed tapping speed to be more affected among the mildly injured than among the moderately injured. Although the latter finding is difficult to interpret, it does indicate that even relatively mild injuries may cause sustained deficits.

The usefulness of the Tapping test in discriminating among severity groups has not been previously demonstrated. Research by the Klonoff group has demonstrated the general sensitivity of the Tapping test to head injury (eg. Klonoff et al., 1969, 1977). They have reported that head-injured children show slower tapping than matched normal controls, at intervals of up to five years post-trauma.

Chadwick and his coworkers (1981) found index finger tapping speed depressed in severely head-injured children longer than one year after injury. At the one year interval, Tapping was one of only three measures which distinguished between head-injured children and normal controls.

In the current research, speed and accuracy in visuospatial function for the dominant hand (Pegboard test) were more negatively effected for the severe group than for the others. Levin and Eisenberg (1979) employed pairwise comparisons across severity groups and did not find Pegboard scores related to severity. However, they defined severity strictly in terms of coma duration and did not give any

weighting to the nature of the injury as was done in this research.

Visuospatial deficits for head-injured children have been demonstrated relative to normals at intervals of one year (Klonoff et al., 1977), and up to 2.25 years (Chadwick et al., 1981). Chadwick and his co-workers found that even after partialling out Performance I.Q. scores, that a measure of visuo-spatial ability still showed deficits. They argue that visuo-spatial tests are most likely to pick up specific deficits not always detected in I.Q. testing.

The severe group in the present study also showed decreased Fluency relative to the moderate and mild head-injury groups. Although Brink et al. (1970) found "speech abnormalities" (unspecified) between one and seven years after severe trauma, Levin and Eisenberg (1979) found no significant relationship between severity group and Fluency in the first half-year post-trauma. Their definition of severity, as mentioned above, may be a deciding factor in this finding. Chadwick et al. (1981) found Fluency was reduced in head-injured patients relative to normals at initial testing but found that the difference had become insignificant one year post-injury.

In summary, previous research has shown that fluency, visuospatial functions, and motor speed are generally sensitive to head injuries, that is, head-injured patients

show deficits on these functions relative to normal children. The present findings indicate that the extent to which deficits occur on these functions varies with the severity of injury. Generally, more severe injuries are associated with significantly more severe deficits, however on the Fluency and non-dominant Pegboard scores, the mild head injuries showed greater deficits than the moderates.

The demonstration in this study of group differences among mildly, moderately and severely head-injured patients on several tests, is an important indicator of differences in the average performances of children in each of the three groups. The analysis of frequency of deficits (defined as scores more than two standard deviations below the mean) provides additional information. The number of individuals in the severe group showing deficits was significantly larger than the number showing deficits in the mild and moderate groups on measures of I.Q. (WISC-R Performance, Full-Scale), receptive language ability (PBY IQ), academic achievement (WRAT R), psychomotor skills (TP total, memory, location), motor speed (TAP total, dominant hand, non-dominant hand), eye-hand coordination (PB TMD), visuospatial and visuospatial memory function (TARGET). Also, a significantly larger number of severely injured children received severe ratings on the overall summary measure of neuropsychological deficits (D.I.)

Findings on these analyses of frequency indicate that

deficits, as defined in this study, are more widespread (in addition to being generally more severe) among the severely injured children. The finding that mildly injured patients show more frequent deficit on the Peabody I.Q. score (PBY IQ) and the reading sub-score of the academic achievement test (WRAT R) are not readily explainable, but do merit further investigation.

The replication of these findings of differential deficit rates in larger samples would possibly prove useful in future prognostic assessments for individual patients, particularly if the frequencies of certain deficit patterns among the severity groups could be established.

Possible Reasons for Neuropsychological Deficits after Head Injury

Earlier in this discussion, reference was made to the explanation evoked to explain the sensitivity of particular types of tests to deficits following head injury in adults. Becker (1975) reports that the "favoured" explanation attributes differential neuropsychological deficits to the dependence of particular tests upon attention, concentration, immediate memory and present efficiency. In a study of children, Chadwick and his coworkers (1981) also reported

that test performances most affected after head injury are those dependent upon the child's ability to respond quickly. Chadwick found in addition, that all the tests showing deficits involved visuo-motor and visuo-spatial skills.

The current findings offer considerable support for this hypothesis. The four tests which were most sensitive to head injury, showing differential deficits across severity groups are all timed tests: the Tapping test, the Pegboard test score for the dominant hand, the verbal Fluency test, and the Tactual Performance Test total score. The last test mentioned here (TPT total) was described above as a test dependent upon tactual-kinesthetic functions. Equally important, it is used as a measure of current adaptive ability (Halstead, 1947), providing measures of immediate memory and speed of performance. Deficits on this test (total score), particularly among the severely head-injured, support the notion that current adaptive capacity is lessened by head injury.

An important adjunct to the above findings that timed, or "speeded" tests show deficits after injury, is the following finding: Among the tests whose scores did not vary with severity of injury, no test incorporated timing into its scoring procedure.

As is evident from the above discussion, the significant differences in the rates of deficit among the three severity

groups were not limited to tests of visuo-spatial and visuo-motor ability. Future studies are required employing both timed and non-timed measures of visuo-spatial and visuo-motor ability, verbal fluency and kinesthetic perceptual abilities. Such studies would possibly disentangle the issue of rate of response from the issue of specific neuropsychological deficits.

Relationship Of Neurologic Deficit To Deficit Index

An analysis was undertaken in order to compare the rates of neurological deficits in the four outcome groups (normal, mild, moderate, or severe deficit) defined according to scores on the Deficit Index, a summary measure of psychological deficit. Results of this analysis revealed strong relationships between the psychological summary measure and severe signs on these neurological indices: the Glasgow Coma Scale, CAT Scan findings, EEG findings, and overall neurological severity rating.

Among those children experiencing severe psychological deficits (Deficit Index score above 30) 89 per cent had Glasgow scores below eight, 86 per cent had abnormal CAT Scans, 75 per cent had EEG abnormalities prior to the time of testing, and 67 per cent received severe overall neurologic

severity ratings.

These findings indicate the utility of the Deficit Index as a summary measure of psychological deficit. Negative signs on the major neurological-neurosurgical diagnostic measures have been shown to be related to this independent measure of brain condition.

Intracranial Hypertension Related To Psychological Outcome : The Relevance of ICP Monitoring for Psychology

Patients undergoing continuous intracranial pressure monitoring as part of the neurosurgical treatment subsequent to head trauma were divided into two groups. The first group was composed of those patients whose pressure was maintained below 20 mmHg, and the second group of those with pressure maintained between 20 and 50 mmHg. No significant differences between the groups emerged on any of the outcome measures. The hypothesized usefulness of ICP as an independent variable in the study of psychological outcome after head injury has therefore not been supported.

This study is the first study to undertake a systematic analysis of the relationship between intracranial pressure and detailed neuropsychological outcome. Previous studies, appearing exclusively in the neurological and neurosurgical

literature, have primarily been concerned with the medical relevance of pressure monitoring. One study (Bruce et al., 1978) has examined ICP in relation to outcome, this being defined in terms of broad categories of capability. No clear relationship was found. Also it is important to note that medical treatments were in several cases administered prior to ICP monitoring. Therefore ICP may not have accurately represented the state of the brain from the time of hospital admission in this study.

There are a number of possible reasons why ICP group membership was not related to outcome in the present research. First, the definition of groups was possibly inappropriate. In this study a patient was said to have ICP maintained between 20 and 50 mmHg if more than one-half of the hourly readings for any day of monitoring exceeded 20 mmHg. This system was contrived as a best "first guess" approach to the definition of "high" and "low" ICP.

In the neurosurgical literature (eg. Ivan et al., 1981) distinctions are made between patients with pressure maintained below 20 mmHg, between 20 and 50 mmHg, and those with pressure maintained above 50 mmHg. The latter condition ("high ICP") typically results in death while low and moderate pressures are associated with more optimistic medical outcomes.

The definition of "moderate" and "low" ICP is

problematic in the sense that relatively brief durations of highly elevated ICP may have neurological, and perhaps psychological, repercussions. The neurosurgical concern is to maintain pressure below a specified level; little attention is paid brief and controllable periods of elevated pressure.

Because "critical periods" of elevation at different pressures have not yet been defined, the dichotomous classification used in this study may be too crude to be sensitive to any existing psychologic effects of intracranial hypertension. Because this difficulty was anticipated, the correlations between a number of continuous measures of ICP and psychological outcome were considered.

Only three of 64 correlations were significant (verbal Fluency and Spelling correlated with average, and average and peak ICP respectively). This result presents little encouragement for further investigations of the possible relationships between pressure in the brain and measureable deficits in the first year to two years following injury. However, because of the retrospective nature of this study, only hourly readings of ICP were available with potentially vast amounts of information left unavailable. Arguably, only prospective studies of the ICP-outcome relationship should be conducted in the future, and these should be limited to studies where a continuous record can be kept of ICP

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fluctuations:

Neuropsychological Performance in Relation to Coma Severity

A major difficulty in the comparison of outcome across head injury samples has been caused by the lack of standardized neurologic criteria available for patient classification. The Glasgow Coma Scale (GCS) was introduced by Teasdale and Jennett (1974) in order to allow standardized rating of the severity of coma. Since its introduction, the scale has been shown to have good inter-rater reliability (Teasdale et al., 1974) and internal consistency (Levin & Eisenberg, 1979). Furthermore, Jennett et al. (1977) in comparing the relationship between GCS scores and outcome in three centres, found that mortality and morbidity rates were very similar for patients with the same GCS scores, despite differences in medical treatments and other variables.

In the present research, GCS scores at the time of admission (assigned retrospectively) were positively correlated with scores on numerous psychological tests. The test areas include intelligence (WISC-R Verbal, Performance, Full scale), abstract reasoning (Category test total score), language (total Aphasia score, verbal Fluency), sensory function (finger Agnosia for the left

hand), psychomotor ability (Tactual Performance Test memory, location, total scores), motor steadiness and speed (Pegboard test dominant hand score), and visual-motor sequencing (Trails test total score). This coma scale, which is used as an index of severity of head injury, is associated with performances in essentially all of the major areas of neuropsychological function.

The Glasgow scale has made possible the standardized investigation of relationships between injury severity and subsequent deficits. Despite this potential, few studies have investigated the relationship in a detailed fashion. The largest studies to date (Becker et al., 1977; Jennett et al., 1977) examined samples composed of both children and adults. These studies found low Glasgow scores associated with poor outcome, and vice versa. However, the measure of outcome employed in both cases was the Glasgow Outcome Scale (Jennett & Bond, 1975), a simple five-point scale which only distinguishes between broadly defined categories of recovery (eg. "good" recovery, "severe" deficit, etc.). In addition, neither of these research teams examined the relation between coma and outcome for children as a separate sub-group.

Two studies, employing only children, examined the relation between the Glasgow scale and the same simplistic outcome scale (Bruce et al., 1978; 1979). They found that all those children who died subsequent to hospitalization for

head injury had GCS scores of four points or less. Those with GCS scores of five or more points showed only moderate disabilities, or good to excellent recovery. A positive correlation was found between best motor response and outcome in the earlier study.

The only study to examine neuropsychological outcome in relation to GCS scores (Levin & Eisenberg, 1979) found visuospatial and memory deficits were more likely to occur in patients with low verbal scores (a ~~sub~~ scale of the Glasgow). However, the composite functions of language, somatosensory ability and motor speed were not significantly related to GCS scores.

The positive findings concur with those of the present research. The lack of significant findings in the other areas may be attributable to one of two reasons: 1) Levin and Eisenberg did not use the eye-opening scale of the GCS, but relied only on the verbal and motor scores, or 2) the use of "composite" measures (single scores calculated for a number of tests of the same function). The latter option is more likely since the current research has shown that certain measures of a function may be related to GCS scores while other measures of the same function are not. Reasons for this differential sensitivity cannot be determined from this research.

The present findings confirm the usefulness of the GCS

as an independent measure in the study of paediatric head injury. The existence of a significant relationship between the frequency of Glasgow scale deficits (score less than eight) and overall severity rating (based on the nature and severity of injury) attests to the validity of the GCS as a measure of severity of injury. Strong negative correlations between the GCS scores on the one hand, and duration of hospitalization, and duration of altered consciousness on the other, further confirms this validity.

Relation Of Coma Duration With Psychological Outcome

Duration of coma is a useful predictor of outcome following head injury in adults (Akerlund, 1959; Heiskanen & Sipponen, 1970; Lecuire, Dechaume, & Deruty, 1970; Overgaard et al., 1973). Its prognostic usefulness in children's head injuries is less certain (Johnston & Mellits, 1980). There are a number of reasons for this uncertainty.

Johnston and Mellits (1980) report that in several large studies of both children and adults, results have not been reported for children as a specific subgroup (Jennett et al., 1978) or have been reported for children only as part of a large subgroup of all those under 20 to 30 years of age (Becker et al., 1977; Heiskanen & Sipponen, 1970.)

Sipponen, 1970; Becker et al., 1977).

Among those studies following-up only children, coma durations have ranged from a number of hours (Bruce et al., 1978) to several weeks (eg. Richardson, 1963), and injury-test intervals have ranged from several months (Hjern and Nylander, 1962) to 14 years (Richardson, 1963). Such extreme heterogeneity has made intra-study comparisons very difficult. The use of incongruous coma definition systems has further added to the difficulty (Stover & Zeiger, 1976).

The potential advantages associated with the use of the GCS have been described above. Again however, this potential has not been met. Only a single study of children employing the GCS has examined the relationship between coma duration and neuropsychological outcome (Levin & Eisenberg, 1979). Unfortunately, although these authors defined severity of coma in terms of GCS scores, they did not explicitly define the criteria used to determine the duration of coma.

Their results indicate that longer coma duration is associated with more severe deficits in memory and visuospatial functioning. These findings concur with the relationship they found between GCS scores and outcome.

In the current study, the duration of altered consciousness was used as an alternative measure to coma since there are a number of problems in the definition of exactly when coma ends (Jennett, 1972).

The duration of altered consciousness was defined in two ways in this study : 1) time expired before full score is attained on all three subscores of the GCS (verbal, motor, eye-opening), and 2) time expired before full score is attained on the verbal and motor responsiveness scales.

The second definition was considered because recovery of speech functioning is often substantially delayed relative to the recovery of the other functions after head injury, and it was considered that it may not reflect the severity of injury. However, the second measure of duration of altered consciousness correlated with fewer outcome measures, and the correlations attained were weaker than those for the full measure. Therefore the first definition was deemed more appropriate, and is discussed here.

Results indicate that duration of altered consciousness is significantly negatively correlated with post-traumatic intelligence (WISC-R Performance and Full scale), abstract reasoning (Category test total), psychomotor function (Tactual Performance Test memory, location, total), sensory-perceptual function (Finger Agnosia left hand), motor speed (Tapping test dominant, nondominant, total scores ; Pegboard test dominant hand time), and language (Aphasia total score ; Fluency test).

The duration of altered consciousness appears therefore to be a useful measure of the severity of injury, and one

which may be usefully applied to the prediction of outcome, particularly in the motor functioning areas, where the correlations are strongest. Future research should concentrate upon the definition of "critical ranges" of altered consciousness, with which could be associated statements of the relative probability of the recovery of particular functions.

Differential Recovery Of Psychological Functions

Analyses were conducted (repeated measures ANOVAs) in order to examine changes in psychological test scores between initial testing within the first half-year after injury and re-testing approximately one year later. Results from this analysis are merely tentative however, because only 12 patients were tested within the first half-year and re-tested one year later, and could therefore be used in this analysis.

A significant interaction was found between test latency and injury severity only for the Aphasia Screening Battery total score. The severe group showed severe deficits initially and had significant improvement by the second testing, whereas the mild/moderate group showed essentially unimpaired performance at both testings. The only other significant change in scores over time occurred for WISC-R

Performance scores. The change over time indicated a recovery process which is not related to severity of injury.

Because of the small number of patients available for this analysis, great confidence cannot be placed in the results.

However, they do generally indicate the transitory nature of language-related deficits occurring after severe head injury. This significant finding is consistent with previous findings (eg. Chadwick et al., 1981), however, the lack of significant findings in the other test areas should not be interpreted to mean that recovery does not occur, only that it was not significant for the sample studied, in the time interval specified.

Behavioural Ratings Subsequent To Head Injury

Reports of children's behavioural disorders following head injury have typically been based upon questionnaire responses or reports from parental interviews. In this research, the Conners Parents Behaviour Rating Scales were used as measures of post-traumatic adjustment. These scales were completed by one or both parents at the time of initial clinical interview held prior to neuropsychological testing.

Previous studies examining the rates of behavioural or

psychiatric disorders in head-injured samples have tended to report greatly variant rates of deficit. This variation has been attributed to differences in the samples employed, particularly to differences in the premorbid adjustment of the children considered (eg. Harrington & Lettemendia, 1958).

Those children with markedly abnormal premorbid histories were screened from this study, however, in a retrospective study, full control over this variable is unlikely. The concern in the present study was to examine the relationships between neurologic indices of the nature and severity of injury and behavioral ratings, rather than to examine absolute rates of disorder.

Results indicate that only scores on the sixth Connors scale, a measure of perfectionism, differed significantly among severity groups with the moderate group showing significantly more perfectionism than the severe group. This finding is difficult to interpret, particularly in light of the lack of other findings. It is probably an artifactual finding.

The general lack of significant group differences on this standardized assessment measure confirms previous findings that severity of injury is not related to subsequent behavioural deficits (Harrington & Lettemendia, 1958 ; Schaffer et al., 1975). Schaffer found no relation between psychiatric disorders and locus or severity of injury.

Results also indicated no correlation between behavioural ratings and depth of coma as measured by the Glasgow Coma Scale. No differences were found between the ratings for the high and low ICP groups either.

A peculiar finding in this study was a negative correlation between coma duration and the first, second, fourth and sixth Conners scales (conduct problem, anxiety, learning problems and perfectionism). This would indicate that longer coma is associated with fewer problems in adjustment. This finding may have resulted from the excellent recovery of a small number of patients after extremely prolonged coma. These children may have shown gross motor, sensory, and intellectual problems, thereby limiting their social interactions and providing for these children a sheltered environment. If this is the case, then parental ratings of behaviour would be misleading and perhaps altogether inappropriate. Because of the retrospective nature of this study, further investigations were impossible, and this possibility could not be evaluated.

The behavioural measures included in this research were used to examine the relative levels of disorder across groups, and not the absolute levels. Nevertheless, the mean levels of deficit for all three groups (see Appendix 2) make it clear that severe behavioural problems did not occur. Some previous studies have shown personality or behavioural

deficits to be common after head trauma. However, the vast majority of these studies used subjective diagnoses of behavioural problems and did not attempt to exclude premorbidly abnormal children from their samples.

The use of standardized behaviour rating scales in the present study, and the exclusion of children with known premorbid abnormalities give considerable weighting to the finding that head injury does not cause personality disorders.

Patterns of Deficit in Mildly, Moderately, and Severely Head-Injured Children

Patterns of neuropsychological test performance were analysed by means of a standardized test profile matching program (Knights, 1973 ; Knights & Watson, 1968 ; Knights & Stoddart, 1981). This automated program computes a coefficient of profile similarity (Cohen, 1969) derived from the work of Cattell (1949), which is influenced by both the level of individuals performances and the patterns of these performances. Reitan (1967) has described the importance of not relying solely upon levels of performance in neuropsychological diagnosis.

The profile approach is typically used for

intra-individual comparisons, and thereby yields information not available from statistical comparisons among group means.

In this research, a "prototypic" or representative profile was constructed for each of the three severity groups. Each of these profiles was composed of the average scores for each group on each of the subtests. Stated differently, three profiles were created to represent the average pattern of deficits for the three head injury groups considered.

In the first profile matching analysis conducted, the three average profiles were compared with each other. Cohen's profile similarity coefficient indicates that the average pattern of strengths and weaknesses for the mild group resembled the pattern for the moderate group to a slightly greater extent than the moderate pattern resembled the severe pattern. This is confirmed through visual examination of the plotted profiles. Visual examination also reveals that scores for the moderate group exceed those for the mild group on a considerable number of tests. Although the differences tend to be small, this suggests that the definition of moderate head injury in neurologic terms is not very informative in terms of predicting outcome. Where moderate scores do fall between those for the mild and severe groups, they tend to be closer to the mild scores. These findings indicate that perhaps the moderate category should

be merged into the mild group for future research, and that continuous measures of severity (e.g., coma, ICP, etc.) should be used in addition to group comparisons.

The general patterns of deficits as seen in the profiles for the three severity groups tend to be similar. This indicates that head injuries in general (irrespective of severity) result in common patterns of strengths and deficits.

In the second analysis, the profile matching program was used to select the best ten matches (from among the 51 head-injured patients) for each of the three average profiles. For the severe profile, seven of 10 matches had severe injuries, the magnitude of the correlations ranging from .67 to .53. Five of 10 matches for the moderate profile had moderate head injuries; correlations ranged from .58 to .46. And, four of ten matches for the mild group had mild injuries with correlations in the range from .53 to .44.

This finding indicates that the pattern of deficits following severe head injury is more distinctive than those following moderate, and particularly mild head injuries. The fact that the profile matching program consistently matched profiles with similar neurologic characteristics is an important finding, both in terms of the consistency of patterns subsequent to head injury, and in terms of the appropriateness of the matching technique for use with

head-injured children. The use of computer programs to simultaneously match large numbers of subtest scores greatly improves upon human clinical judgements dependent upon memory limitations.

The long-term goal for such matching analyses is to allow the classification of head injury patients on the basis of psychological test score pattern rather than on the basis of neurological and neurosurgical indices of injury. The present study constitutes an important first step toward this goal.

Overview and Implications of this Research

The purpose of this research was to investigate the relationships between neurologic indices of the severity of head injury and psychological deficits post-trauma. Previous research has demonstrated that head-injured children show deficits relative to normals in the areas of intelligence, personality, motor and sensory functions, academic achievement and performance. The present study has shown that children with severe head injuries show significantly larger deficits than mildly and moderately-injured children in performance I.Q., speed of motor performance, visuospatial functions, tactual-kinesthetic functions and current adaptive

abilities. This finding constitutes an early step in the development of a prognostic system by which severity of injury, defined in terms of acute neurologic status, may be used to predict detailed psychological outcome.

Previous attempts to predict outcome from measures of neurologic status have been limited largely to the prediction of gross categories of outcome from measures of coma duration. The limited usefulness of employing gross categories of outcome was commented upon by Jennett (1972) who discussed a paper where patients with hemiplegia, dysphasia, and visual field defects were categorized as "excellent" recoveries, and those categorized as "good" recoveries in some instances needed help to walk across a room.

This research has shown the feasibility of relating a standardized, reliable measure of coma severity to specific measures of neuropsychological function. Also, the duration of altered consciousness, an easily assessed measure of neurologic status, has been shown to be a useful predictor of outcome, particularly in the area of motor functions.

Because a major cause of brain damage in blunt paediatric head injury is intracranial hypertension, it was hypothesized that intracranial pressure would be a useful predictor of specific psychological deficits. Although no significant relationships were identified in this initial

investigation, the rationale and guidelines for future research did clearly emerge.

The deficit index, a summary measure of psychological dysfunction, was found to be a good index of the severity of injury. It corresponded closely with findings for the major neuro-diagnostic tools.

Analyses of the neuropsychological profiles for mildly, moderately, and severely head-injured children indicated that there exist some common elements in the pattern of deficits subsequent to head injury. The comparison of patterns of deficits may give additional meaning to the isolated findings of particular deficits which have been accumulating in the head injury literature to date.

Profile comparisons have demonstrated that the "moderate" head injury rating, as defined in this study, does not clarify the neurologic-psychologic relationship subsequent to head injury.

An important implication of this research is that coma duration need not be considered the only neurologic index of use to the psychologist. This research has shown that psychological outcome is related to the nature and severity of the injury. Different predictors have been shown to be useful in different areas of outcome.

The demonstration in this study, and other studies, that severe deficits do occur in patients experiencing brief or no

periods of coma necessitates the investigation of further neurologic-psychologic relations, both for the purpose of predicting outcome, and for the understanding of the mechanisms leading to psychological deficit after paediatric head trauma.

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APPENDIX 1

GLASGOW COMA SCALE *

EYES OPEN

spontaneously	4
to speech	3
to pain	2
none	1

BEST VERBAL RESPONSE

oriented	5
confused	4
inappropriate	3
incomprehensible	2
none	1

BEST MOTOR RESPONSE

obeys commands	5
localizes pain	4
flexion to pain	3
extension to pain	2
none	1

* Scale from Teasdale & Jennett (1974)

APPENDIX 2

MEANS AND STANDARD DEVIATIONS FOR PSYCHOLOGICAL TEST SCORES
FOR MILD, MODERATE, AND SEVERE HEAD INJURY GROUPS

TEST	MILD	MODERATE	SEVERE	F RATIO	SIGNIF
WISCR-V	44.75 (09.59)	46.17 (11.99)	40.58 (12.77)	01.05	N.S.
WISCR-P	48.87 (12.38)	45.88 (12.55)	36.27 (14.90)	03.77	*
WISCR-F	46.71 (11.23)	45.69 (12.28)	37.55 (14.58)	02.38	N.S.
PBY IQ	48.42 (17.92)	50.24 (10.96)	49.79 (14.49)	<1	N.S.
WRAT R	49.58 (06.98)	51.65 (10.69)	46.94 (13.17)	<1	N.S.
WRAT S	49.00 (07.48)	49.41 (11.78)	43.61 (16.50)	<1	N.S.
WRAT A	43.82 (09.28)	44.78 (10.30)	40.89 (11.45)	<1	N.S.
CAT T	50.38 (15.62)	44.18 (15.86)	38.69 (16.26)	02.16	N.S.
TPT T	41.18 (14.59)	43.08 (15.45)	27.96 (17.24)	03.43	*
TPT MEMORY	47.91 (07.62)	40.21 (13.52)	40.02 (08.26)	02.83	N.S.
TPT LOCATN	42.74 (16.23)	38.38 (19.67)	30.88 (19.29)	01.36	N.S.
TAP T	48.82 (11.11)	47.85 (07.65)	30.16 (13.91)	13.37	***
TAP DH	53.56 (11.43)	54.65 (10.89)	38.27 (17.56)	07.67	***
TAP NDH	51.76 (11.51)	54.79 (11.35)	31.29 (19.49)	13.00	***
FGAG R	36.24 (18.87)	40.00 (18.78)	34.39 (20.75)	<1	N.S.
FGAG L	40.76 (14.89)	46.36 (15.88)	33.76 (18.76)	02.26	N.S.
R-L ORIENT	40.52 (21.92)	36.39 (22.46)	36.11 (24.28)	<1	N.S.
TOT AP	47.51 (11.07)	50.20 (12.36)	40.58 (15.57)	02.29	N.S.
PB TMD	46.23 (13.43)	45.98 (17.47)	31.84 (23.48)	03.39	*
PB TMN	42.03 (18.41)	34.36 (22.61)	35.53 (23.32)	<1	N.S.
SENMEM	38.83	50.38	47.35	01.02	N.S.

APPENDIX 2 continued

	(15.83)	(17.38)	(19.71)		
FLUNCY	45.31	51.17	38.19	03.26	*
	(16.50)	(15.40)	(12.46)		
TARGET	44.99	47.32	41.40	<1	N.S.
	(12.85)	(12.59)	(13.47)		
TRAILTOT	42.23	46.27	34.76	<1	N.S.
	(23.44)	(09.78)	(20.18)		
CONNERS1	04.25	03.93	02.20	<1	N.S.
	(04.07)	(04.50)	(03.33)		
CONNERS2	03.94	03.00	01.80	01.47	N.S.
	(03.09)	(03.88)	(01.40)		
CONNERS3	05.56	06.50	03.90	<1	N.S.
	(04.80)	(04.85)	(05.13)		
CONNERS4	02.75	02.50	00.90	02.85	N.S.
	(01.95)	(02.14)	(01.91)		
CONNERS5	02.44	02.07	00.90	02.32	N.S.
	(02.03)	(01.90)	(01.10)		
CONNERS6	01.81	03.21	00.20	05.92	**
	(02.26)	(02.61)	(00.42)		
CONNERS7	00.60	00.14	00.10	<1	N.S.
	(00.25)	(00.36)	(00.32)		
8	00.06	00.14	00.10	<1	N.S.
	(00.25)	(00.36)	(00.32)		

bracketed values are standard deviations

* =signif.05
 ** =signif.01
 *** =signif.001

APPENDIX 3

MEANS AND STANDARD DEVIATIONS FOR ICP GROUPS(<20 mmHg and >20 mmHg) ON PSYCHOLOGICAL TEST SCORES

TEST NAME*	ICP GRP 1	ICP GRP 2
WISCR-V	41.26 (08.72)**	39.71 (17.46)
WISCR-P	36.93 (11.59)	35.51 (18.98)
WISCR-F	38.33 (10.14)	36.66 (19.35)
PBY IQ	48.24 (12.47)	51.80 (17.59)
WRAT R	45.78 (09.10)	48.10 (17.19)
WRAT S	40.67 (15.61)	46.55 (18.29)
WRAT A	43.00 (10.58)	38.47 (12.75)
CAT T	39.98 (11.34)	37.04 (21.99)
TPT T	37.13 (07.75)	16.96 (19.76)
TPT MEMORY	41.95 (06.49)	37.70 (10.28)
TPT LOCATN	40.07 (15.29)	19.86 (18.98)
TAP T	30.12 (14.66)	30.22 (14.11)
TAP DH	36.32 (21.37)	41.06 (11.05)
TAP NDH	27.35 (19.46)	36.91 (19.55)
FGAG R	40.26 (18.23)	28.86 (22.71)
FGAG L	32.79 (19.90)	35.22 (18.63)
R-L ORIENT	36.04 (25.27)	36.21 (24.77)
TOT AP	38.43 (13.85)	43.33 (18.30)
PB TMD	34.89 (21.11)	27.47 (27.63)
PB TMN	37.67 (26.05)	32.47 (20.35)
SENMEM	44.65 (16.50)	50.05 (23.76)
FLUNCY	38.63 (14.95)	37.57 (08.84)
TARGET	41.69 (10.21)	41.11 (16.99)
TRAILTOT	38.08 (19.29)	32.10 (22.70)

* for explanations of abbreviations see Table 3.

** bracketed values are standard deviations.

APPENDIX 4

GLASGOW COMA SCALE CORRELATIONS WITH SCORES ON CONNERS PARENTS' RATING SCALES

CONNERS1	.145	N.S.
CONNERS2	.155	N.S.
CONNERS3	.039	N.S.
CONNERS4	.203	N.S.
CONNERS5	.178	N.S.
CONNERS6	.090	N.S.
CONNERS7	-.071	N.S.
CONNERS8	.044	N.S.

APPENDIX 5

MEANS AND STANDARD DEVIATIONS FOR TESTING AND RE-TESTING ON
PSYCHOLOGICAL MEASURES FOR MILD/MODERATE AND SEVERE HEAD
INJURY GROUPS

TEST NAME		MILD/MODER.	SEVERE
WISCR V	test	1 50.40(11.23)	36.77(13.47)
	test	2 50.20(06.06)	43.12(12.85)
WISCR P		1 48.78(04.46)	26.92(15.04)
		2 53.20(08.08)	40.80(16.78)
WISCR F		1 49.46(08.44)	31.04(15.29)
		2 52.14(07.00)	41.60(16.67)
CAT T		1 51.76(08.40)	35.43(21.74)
		2 56.00(11.93)	47.85(17.15)
TAPT		1 54.16(07.83)	17.60(09.17)
		2 50.42(08.44)	23.20(10.10)
FGAG R		1 52.67(02.07)	27.33(18.14)
		2 34.33(24.21)	42.67(15.88)
FGAG L		1 51.78(08.12)	24.88(19.65)
		2 45.00(16.19)	33.42(27.44)
APHASIA		1 52.98(05.64)	36.55(12.75)
		2 52.82(06.84)	48.57(12.58)
SENMEM		1 43.33(11.55)	18.66(09.02)
		2 47.80(08.40)	25.32(18.93)
R-L DISC		1 25.58(28.05)	34.50(26.77)
		2 25.00(27.39)	34.28(26.65)
PB TMD		1 52.00(13.46)	44.05(26.20)
		2 53.04(16.24)	46.80(16.81)

APPENDIX 6

CORRELATIONS BETWEEN INJURY-TEST INTERVAL AND PSYCHOLOGICAL TEST SCORES

WISCR V	-.078	N.S.
WISCR P	-.011	N.S.
WISCR F	-.039	N.S.
PBY IQ	.067	N.S.
WRAT R	.161	N.S.
WRAT S	.163	N.S.
WRAT A	.031	N.S.
CAT T	-.013	N.S.
TPT MEMORY	.097	N.S.
TPT LOCATN	.058	N.S.
TPT TOT	-.166	N.S.
FGAG R	-.232	N.S.
FGAG L	.016	N.S.
TAP DH	.040	N.S.
TAP NDH	.016	N.S.
TAP T	.114	N.S.
PB TMD	.146	N.S.
PB TMN	.181	N.S.
TOT AP	.015	N.S.
R-L ORIENT	.079	N.S.
SENMEM	.188	N.S.
FLUNCY	-.139	N.S.
TARGET	.047	N.S.
TRAILTOT	-.262	N.S.

APPENDIX 7

Abbreviations and Full Test Names for the Knights-Norwood Neuropsychological Battery

TEST	FULL TEST NAME
CA	CHRONOLOGICAL AGE
WISCRV	WECHSLER INTELLIGENCE SCALE FOR CHILDREN (REVISED) Verbal Score
WISCRP	Performance Score
WISCRF	Full Scale Score
INFORM	Information
SIMIL	Similarities
ARITH	Arithmetic
VOCAB	Vocabulary
COMPRN	Comprehension
DIGSPN	Digit Span
PCTCMP	Picture Completion
PCTARR	Picture Arrangement
BLKDGN	Block Design
OBJASS	Object Assembly
CODE	Coding
MAZE	Mazes
PBY-MA	PEABODY PICTURE VOCABULARY TEST (Hearing) Mental Age
PBY-IQ	(Hearing) Intelligence Quotient
PBYRMA	(Reading) Mental Age
PBYRIQ	(Reading) Intelligence Quotient
WRATRG	WIDE RANGE ACHIEVEMENT TEST
WRATSG	Spelling Grade
WRATAG	Arithmetic Grade
WRAT-S	Reading Standard Score
WRAT-A	Arithmetic Standard Score
CAT-1	CATEGORY TEST (Score 1)
CAT-2	Score 2
CAT-3	Score 3
CAT-4	Score 4
CAT-5	Score 5
CAT-6	Score 6
CAT-T	Total Score
TPT-DH	TACTUAL PERFORMANCE TEST (Dominant Hand Score)
TPT-ND	Non-dominant Hand Score
TPT-BH	Both Hands Score
TPT-T	Total Time Score
MEMORY	TPT Memory Score
LOCATN	TPT Location Score

APPENDIX 7 continued

TAP-DH	TAPPING TEST (Dominant Hand Score)
TAP-NH	Non-dominant Hand Score
TAP-DF	Dominant Foot Score
TAP-NF	Non-dominant Foot Score
TAP-T	Total Score
TAT-R	TACTILE IMPERCEPTION TEST (Right Side Score)
TAT-L	Left Side Score
AUD-R	AUDITORY IMPERCEPTION TEST (Right Side Score)
AUD-L	Left Side Score
VIS-R	VISUAL IMPERCEPTION TEST (Right Side Score)
VIS-L	Left Side Score
FGAG-R	FINGER AGNOSIA TEST
FGAG-L	Left Side Score
FWT-R	FINGER TIP WRITING TEST (Right Side Score)
FWT-L	Left Side Score
TACF-R	TACTILE FORMS TEST (Right Side Score)
TACF-L	Left Side Score
ANOMIA	Anomia
DYSGRA	Dysgraphia
DYSLEX	Dyslexia
DYSPRX	Dyspraxia
DYSCAL	Dyscalculia
IDLDYS	Ideational Dyspraxia
EXPAPH	Expressive Aphasia
VISDYS	Visual Dysgnosis
AUDDYS	Auditory Dysgnosis
ORLSPL	Oral Spelling
WRTSPL	Written Spelling
PICWRD	Picture-Word Test
WRDPIC	Word-Picture Test
R-L	Right-Left Discrimination
BODORN	Body Orientation
TOT-AP	TOTA APHASIA SCORE
DYN-R	DYNOMETER (Right Hand)
DYN-L	Left Hand Score
NAM-R	NAME WRITING (Right Hand)
NAM-L	Left Hand Score
MZ-TMD	MAZE TEST (Time Dominant Hand)
MZ-CTD	Counter Dominant Hand
MZ-SWD	Time Dominant Hand
MZ-TMN	Time Non-dominant Hand
MZ-CTN	Counter Non-dominant Hand
MZ-SWN	Time Non-dominant Hand
HL-TMD	HOLES TEST (Timer Dominant Hand)
HL-CTD	Counter Dominant Hand

APPENDIX 7 continued

HL-TMN	Time Non-dominant Hand
HL-CTN	Counter Non-dominant Hand
PB-TMD	PEGBBOARD TEST (Time Dominant Hand)
PB-ERD	Errors Dominant Hand
PB-TMN	Time Non-dominant Hand
PB-ERN	Errors Non-dominant Hand
BOSTON	BOSTON SPEECH TEST
AUDCLO	SOUND BLENDING TEST
SEMEM	SENTENCE MEMORY TEST
FLUNCY	FLUENCY TEST
SPPERC	SPEECH PERCEPTION TEST
SEARYM	SEASHORE RHYTHM TEST
TARGET	TARGET TEST
KNOXMA	KNOX CUBE TEST (Mental Age)
DEVLDR	DEVELOPMENTAL DRAWINGS
TR-A	TRAILS TEST (Time Trial A)
TR-AER	Errors Trial A
TR-B	Time Trial B
TR-BER	Errors Trial B
TR-TOT	Total Time
TR-TER	Total Errors
CON-CP	CONNERS TEACHERS (Conduct Problem)
CON-IP	Inattentive-Passive
CON-TA	Tension-Anxiety
CONHYP	Hyperactive

APPENDIX 8

Mean Values for All Psychological Tests for Mild, Moderate and Severe Head Injury Groups

TEST	MILD	MODERATE	SEVERE
CA			
WISCRV	44.75 (09.59)	46.17 (11.99)	40.58 (12.77)
WISCRP	48.47 (12.38)	45.88 (12.55)	36.27 (14.90)
WISCRF	46.71 (11.23)	45.69 (12.28)	37.55 (14.58)
INFORM	43.33 (09.58)	44.37 (11.72)	42.71 (11.75)
SIMIL	43.75 (08.76)	46.26 (10.46)	42.08 (12.10)
ARITH	47.08 (08.94)	50.00 (11.09)	42.29 (13.20)
VOCAB	50.00 (14.76)	46.42 (11.89)	45.01 (14.11)
COMPRN	48.34 (09.88)	47.08 (09.74)	42.29 (12.23)
DIGSPN	42.90 (08.89)	46.46 (11.96)	41.25 (12.81)
PCTCMP	48.33 (11.99)	45.84 (07.04)	38.65 (10.90)
PCTARR	47.45 (12.66)	44.39 (10.67)	37.55 (13.12)
BLKDGN	50.38 (10.40)	51.04 (12.27)	39.38 (15.68)
OBJASS	49.81 (14.06)	46.67 (14.72)	45.77 (14.33)
CODE	47.65 (10.66)	47.35 (10.87)	35.11 (12.91)
MAZE			
PBY-MA	49.87 (41.34)	43.38 (34.96)	51.25 (43.01)
PBY-IQ	48.42 (17.92)	50.24 (10.96)	49.79 (14.49)
PBYRMA			
PBYRIQ			
WRATRG			
WRATSG			
WRATAG	27.75 (21.60)	31.18 (23.02)	28.71 (21.11)
WRAT-S	49.00 (07.48)	49.41 (11.78)	43.61 (16.50)
WRAT-A	43.82 (09.28)	44.78 (10.30)	40.89 (11.45)
CAT-1	47.58 (14.36)	45.76 (17.51)	47.04 (14.62)
CAT-2	50.20 (09.20)	46.28 (16.83)	46.76 (13.31)
CAT-3	50.64 (11.74)	46.94 (08.43)	43.43 (12.23)
CAT-4	50.89 (09.98)	49.08 (12.07)	42.52 (12.74)
CAT-5	52.39 (11.82)	47.33 (12.85)	42.76 (15.12)
CAT-6	51.71 (12.99)	42.54 (13.62)	46.22 (13.78)
CAT-T	50.38 (15.62)	44.18 (15.86)	38.69 (16.26)
TPT-DH	42.77 (12.71)	48.64 (10.38)	36.48 (15.79)
TPT-ND	42.70 (15.62)	39.68 (16.69)	20.33 (18.08)
TPT-BH	40.95 (15.58)	30.59 (24.89)	20.85 (21.06)
TPT-T	41.18 (14.59)	43.08 (15.45)	27.96 (17.24)
MEMORY	47.91 (07.62)	40.21 (13.52)	40.02 (08.26)
LOCATN	42.74 (16.23)	38.38 (19.67)	30.88 (19.29)
TAP-DH	53.56 (11.43)	54.65 (10.89)	38.27 (17.56)
TAP-NH	51.76 (11.51)	54.79 (11.35)	31.29 (19.49)
TAP-DF	46.67 (10.16)	46.66 (09.31)	30.27 (13.30)

APPENDIX 8 continued

TAP-NF	47.22 (11.18)	41.47 (09.96)	29.00 (13.81)
TAP-T	48.82 (11.11)	47.85 (07.65)	30.16 (13.91)
TAT-R	50.93 (14.67)	54.45 (04.70)	44.84 (18.21)
TAT-L	55.27 (04.80)	55.08 (04.70)	45.48 (20.18)
AUD-R	48.61 (13.25)	47.36 (18.89)	45.77 (15.88)
AUD-L	51.44 (13.75)	52.90 (07.95)	38.44 (23.24)
VIS-R	55.38 (08.29)	52.80 (12.09)	47.27 (19.02)
VIS-L	46.27 (18.76)	45.19 (19.17)	46.65 (16.15)
FGAG-R	36.24 (18.67)	40.00 (18.78)	34.39 (20.75)
FGAG-L	40.76 (14.89)	46.36 (15.88)	33.76 (18.76)
FWT-R	46.82 (12.92)	46.09 (13.43)	32.48 (19.78)
FWT-L	48.81 (17.02)	44.80 (13.43)	36.14 (20.73)
TACF-R	53.37 (03.36)	46.08 (19.64)	50.03 (10.42)
TACF-L	44.04 (19.33)	47.53 (14.85)	45.46 (17.05)
ANOMIA	46.01 (12.76)	42.31 (18.63)	40.56 (16.91)
DYSGRA	50.51 (08.65)	53.54 (08.54)	43.28 (14.27)
DYSLEX	41.53 (17.99)	47.49 (08.89)	38.49 (18.16)
DYSPRX	54.36 (06.97)	48.44 (11.05)	46.13 (15.40)
DYSCAL	48.65 (10.82)	49.18 (10.49)	46.28 (10.89)
IDLDYS	47.90 (11.54)	45.66 (16.23)	47.29 (14.43)
EXPAPH	41.00 (16.52)	50.11 (06.86)	40.50 (23.07)
VISDYS	51.05 (12.25)	53.78 (04.56)	54.35 (02.83)
AUDDYS	38.06 (22.22)	48.82 (10.26)	53.03 (02.89)
ORLSPL	48.26 (12.43)	57.61 (06.30)	53.00 (09.16)
WRTSPL	52.62 (12.26)	60.57 (05.80)	51.48 (12.38)
PICWRD	39.36 (22.35)	51.40 (02.10)	44.91 (16.90)
WRDPIC	48.42 (18.87)	58.19 (05.36)	48.93 (19.32)
R-L	40.52 (21.92)	36.39 (22.46)	36.11 (24.28)
BODORN			
TOT-AP	47.51 (11.07)	50.20 (12.36)	40.58 (15.57)
DYN-R	64.38 (14.60)	62.64 (16.12)	56.69 (12.38)
DYN-L	63.17 (15.35)	61.78 (13.12)	55.21 (12.92)
NAM-R	53.81 (05.92)	51.66 (06.94)	43.71 (17.11)
NAM-L	51.86 (10.12)	48.99 (09.10)	40.04 (19.18)
MZ-TMD	56.08 (07.69)	51.90 (11.87)	30.50 (22.81)
MZ-CTD	59.09 (08.85)	52.49 (16.99)	39.57 (19.84)
MZ-SWD	29.29 (16.49)	32.61 (16.63)	35.22 (18.30)
MZ-TMN	56.05 (09.72)	50.57 (17.02)	30.95 (22.54)
MZ-CTN	57.50 (11.20)	57.11 (11.43)	37.88 (23.01)
MZ-SWN	38.35 (14.99)	32.96 (17.25)	40.65 (18.45)
HL-TMD	53.52 (09.25)	51.77 (08.87)	44.47 (19.64)
HL-CTD	54.54 (09.86)	53.58 (12.22)	51.51 (18.74)
HL-TMN	50.92 (09.56)	49.22 (07.33)	47.45 (17.14)
HL-CTN	51.49 (14.36)	54.75 (12.08)	54.17 (19.04)
PB-TMD	46.42 (13.43)	45.98 (17.47)	31.84 (23.48)
PB-ERD	42.03 (18.41)	34.36 (22.61)	35.53 (23.32)
PB-TMN	47.44 (13.24)	48.76 (15.95)	25.17 (18.57)
PB-ERN	44.71 (15.82)	46.28 (15.51)	28.73 (23.77)
BOSTON			
AUDCLO	45.86 (19.00)	53.94 (09.04)	36.67 (10.45)
SEMEM	38.83 (15.83)	50.38 (17.38)	47.35 (19.71)
FLUNCY	45.31 (16.50)	51.17 (15.40)	38.19 (12.46)

APPENDIX 8 continued

SPPERC			
SEARYM	53.40 (11.40)	54.32 (07.08)	52.81 (11.33)
TARGET	44.99 (12.85)	47.32 (12.59)	41.40 (13.47)
KNOXMA	55.29 (29.87)	62.65 (28.62)	40.00 (31.17)
DEVLDR	38.01 (15.26)	36.87 (16.35)	27.45 (15.52)
TR-A	47.38 (09.44)	49.74 (08.91)	28.74 (20.96)
TR-AER	40.95 (19.96)	52.92 (00.10)	37.62 (20.52)
TR-B	42.19 (23.35)	43.78 (11.96)	38.66 (18.79)
TR-BER	48.48 (10.46)	42.52 (13.99)	39.08 (19.42)
TR-TOT	42.23 (23.44)	46.27 (09.87)	34.76 (20.18)
TR-TER	44.27 (14.95)	45.71 (10.43)	35.83 (20.58)
CON-CP			
CON-IP			
CON-TA			
CONHYP			

*Blanks represent tests which were not included because they were administered to less than 50 per cent of patients.

END

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FIN