A PROSPECTIVE ANALYSIS OF THE RECOVERY OF ATTENTION FOLLOWING PAEDIATRIC TRAUMATIC BRAIN INJURY.

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Submitted in total fulfilment of the requirements of the degree of Doctor of Philosophy

December, 2000

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Produced on acid-free paper
Abstract

Little is known about the recovery of information processing and functional skills following traumatic brain injury during childhood, or of their pattern of recovery, their interaction with ongoing development, and possible predictors of outcome. The present study examined intellectual, information processing (attention, memory and learning) and functional skills (educational and adaptive skills) in a group of children who had sustained a mild (n=27), moderate (n=33) or severe (n=16) traumatic brain injury (TBI) between the ages of 8-12 years. Children were recruited between June 1994 and December 1997 from the Royal Children’s Hospital, Melbourne, Australia. The TBI children were then assessed during the acute (0-3 months), 6, 12 and 24 months post-injury. Pre-injury data showed that the three TBI groups were performing similarly prior to their injuries, suggesting that any post-injury deficits were injury related. Results generally indicated that information processing and functional skills have different developmental/recovery trajectories, and are influenced by both pre-and-post injury factors. Furthermore, while the severe TBI group did show recovery on a number of tasks, they continued to perform below the mild and moderate TBI groups, on most tasks, at 24 months post-injury. The study identified specific deficit areas, which may be translated into appropriate treatment interventions.
Declaration

This is to certify that
(i) the thesis only comprises my original work
(ii) due acknowledgement has been made in the text to all other material used.
(iii) the thesis is less than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.

Cathy Catroppa

Cathy Catroppa
Acknowledgements

First I would like to acknowledge my supervisor, and friend, Dr Vicki Anderson for all her guidance, support and encouragement. Due to Vicki’s continual confidence that completing a Ph.D thesis was within my grasp, I was motivated to complete this research project.

I would also like to thank Joe for his patience over the years, and for assisting me during those occasions when the computer seemed to have a mind of its own!! A special thanks to my parents who supported me for many years and also encouraged me to continue my education. I would also like to note my appreciation for my work colleagues, who either directly or indirectly, have assisted in the completion of this thesis.

Of most importance I note my appreciation for the ongoing support and persistence shown by the children and families who participated. Without their contribution we could not extend our understanding of the sequelae following traumatic brain injury during childhood.
## Table of contents

### Chapter 1:
**Introduction**

### Chapter 2:
**Mechanics of head injury**

- 2.1 Primary and secondary effects of head injury
- 2.2 Determining the severity of head injury
  - 2.2.1 The Glasgow Coma Scale (GCS)
  - 2.2.2 Post Traumatic Amnesia (PTA)
  - 2.2.3 Pupillary Light Response
  - 2.2.4 Radiological indicators of TBI severity
  - 2.2.5 Conclusions
- 2.3 Predictors of outcome
  - 2.3.1 GCS, PTA and Pupillary light response
  - 2.3.2 Radiological predictors - CT, PET, MRI
  - 2.3.3 Pre-morbid characteristics
  - 2.3.4 Family functioning
  - 2.3.5 Age at injury
  - 2.3.6 Time since injury
  - 2.3.7 Conclusions

### Chapter 3:
**Outcomes following TBI**

- 3.1 Introduction
  - 3.1.1 Mild, moderate and severe TBI
- 3.2 Language outcomes
- 3.3 Memory outcomes
- 3.4 Executive outcomes
- 3.5 Psychosocial outcomes
- 3.6 Educational outcomes
  - 3.6.1 Conclusions
Chapter 4:
Models and theories of attention

4.1 Introduction 35
4.2 The study of attention: An information processing approach 36
  4.2.1 Psychological models 36
  4.2.2 Neuropsychological models 38
  4.2.3 Conclusions 43
4.3 Development of attention 43
  4.3.1 Sustained attention 43
  4.3.2 Selective attention (focused) 44
  4.3.3 Shifting attention 45
  4.3.4 Speed of information processing 45
4.4 Conclusions 45

Chapter 5:
Attentional skills following TBI

5.1 Introduction – Attention 47
  5.1.1 Adult literature 47
  5.1.2 Paediatric literature 48
  5.1.3 Conclusions 49
5.2 Speed of processing outcomes 50
  5.2.1 Adult literature 50
  5.2.2 Paediatric literature 53
  5.2.3 Conclusions 54

Chapter 6:
The Present study

6.1 Introduction 55
6.2 Aims 55
6.3 Method 57
  6.3.1 Participants 57
  6.3.2 Measures 59
  6.3.3 General procedure 63
Chapter 7:

Recovery of intellectual ability following paediatric traumatic brain injury

7.1 Introduction 65
7.2 Method 67
  7.2.1 Participants 67
  7.2.2 Measures 67
  7.2.3 Procedure 68
  7.2.4 Statistical analysis 68
7.3 Results 69
7.4 Discussion 77

Chapter 8:

Attention following paediatric traumatic brain injury

8.1 Introduction: The recovery of attention following paediatric TBI 82
8.2 Study 1: Recovery of attention 88
  8.2.1 Method 88
  8.2.2 Participants 88
  8.2.3 Measures 88
  8.2.4 Procedure 90
  8.2.5 Statistical analysis 90
8.3 Results (Study 1) 90
8.4 Discussion (Study 1) 103
8.5 Study 2: Analysis of specific components of attention 110
  8.5.1 Method 110
  8.5.2 Participants 110
  8.5.3 Measures 110
  8.5.4 Procedure 111
  8.5.5 Statistical analysis 111
8.6 Results (Study 2) 111
8.7 Discussion (Study 2) 112
8.8 General conclusions 115
Chapter 9:
Recovery in memory function following traumatic brain injury in children.

9.1 Introduction 116
9.2 Method 119
  9.2.1 Participants 119
  9.2.2 Measures 119
  9.2.3 Procedure 121
  9.2.4 Statistical analysis 121
9.3 Results 121
9.4 Discussion 131

Chapter 10:
Recovery of educational skills following paediatric traumatic brain injury:
Functional outcomes.

10.1 Introduction 136
10.2 Method 138
  10.2.1 Participants 138
  10.2.2 Measures 139
  10.2.3 Procedure 139
  10.2.4 Statistical analysis 140
10.3 Results 140
10.4 Discussion 145

Chapter 11
Predictors of educational and adaptive outcome

11.1 Introduction 149
11.2 Method 153
  11.2.1 Materials 153
  11.2.2 Statistical analysis 153
11.3 Results 154
11.4 Discussion 158
Chapter 12:

General Conclusions.

12.1 Summary 163
12.2 Aims 164
12.3 Limitations of Study 164
12.4 Future Directions 165

Bibliography 166
Appendix 1 199
Tables

Table 2.1 Glasgow Coma Scale (GCS) 10
Table 6.1 Demographic information for the sample 58
Table 6.2 Injury and medical characteristics of the sample 59
Table 6.3 Summary of test protocol 60
Table 7.1 Vineland Adaptive Behavior Scale domain scores-pre-injury 69
Table 7.2 Verbal subtest measures 75
Table 7.3 Performance subtest measures 76
Table 7.4 Predictors of intellectual ability two years post-TBI 77
Table 8.1 Sustained attention: summary scores 96
Table 8.2 Experimental manipulations of CPT paradigm 111
Table 8.3 Results for Conditions 1, 2, and 3 112
Table 9.1 Immediate memory results 122
Table 9.2 Short-term memory/encoding results 123
Table 9.3 Multi-trial learning results 125-126
Table 9.4 Predictors of memory ability two years post-TBI 131
Table 10.1 Pre-injury information for the sample 141
Table 10.2 Adaptive functioning skills 142
Table 11.1 Significant predictors of attention during the acute stage 155
Table 11.2 Significant predictors of educational/adaptive outcomes at 24 months 158
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 6.1</td>
<td>Information processing model</td>
</tr>
<tr>
<td>Figure 7.1</td>
<td>Verbal IQ (VIQ) at 0-3,12, and 24 months post-TBI</td>
</tr>
<tr>
<td>Figure 7.2</td>
<td>Performance IQ (PIQ) at 0-3,12, and 24 months post-TBI</td>
</tr>
<tr>
<td>Figure 7.3</td>
<td>Full scale IQ (FIQ) at 0-3,12, and 24 months post-TBI</td>
</tr>
<tr>
<td>Figure 7.4</td>
<td>Verbal Comprehension (VC) Index at 0-3,12, and 24 months post-TBI</td>
</tr>
<tr>
<td>Figure 7.5</td>
<td>Perceptual Organisation (PO) Index at 0-3,12, and 24 months post-TBI</td>
</tr>
<tr>
<td>Figure 7.6</td>
<td>Processing Speed (PS) Index at 0-3,12, and 24 months post-TBI</td>
</tr>
<tr>
<td>Figure 7.7</td>
<td>Freedom from Distractability Index at 0-3,12, and 24 months post-TBI</td>
</tr>
<tr>
<td>Figure 8.1</td>
<td>Sociability Domain (parent) at 0-3, 6, 12, and 24 months post-TBI</td>
</tr>
<tr>
<td>Figure 8.2</td>
<td>Attention Domain (parent) at 0-3, 6, 12, and 24 months post-TBI</td>
</tr>
<tr>
<td>Figure 8.3</td>
<td>Restlessness Domain (parent) at 0-3, 6, 12, and 24 months post-TBI</td>
</tr>
<tr>
<td>Figure 8.4</td>
<td>Sociability Domain (teacher) at 0-3, 6, 12, and 24 months post-TBI</td>
</tr>
<tr>
<td>Figure 8.5</td>
<td>Attention Domain (teacher) at 0-3, 6, 12, and 24 months post-TBI</td>
</tr>
<tr>
<td>Figure 8.6</td>
<td>Restlessness Domain (teacher) at 0-3, 6, 12, and 24 months post-TBI</td>
</tr>
<tr>
<td>Figure 8.7</td>
<td>Number correct across the 4 5-minute time blocks</td>
</tr>
<tr>
<td>Figure 8.8</td>
<td>Number of omission errors across the 4 5-minute time blocks</td>
</tr>
<tr>
<td>Figure 8.9</td>
<td>Number of commission errors across the 4 5-minute time blocks</td>
</tr>
<tr>
<td>Figure 8.10</td>
<td>Number of missed responses across the 4 5-minute time blocks</td>
</tr>
<tr>
<td>Figure 8.11</td>
<td>Mean reaction time across the 4 5-minute time blocks</td>
</tr>
<tr>
<td>Figure 8.12</td>
<td>Number of impulsive responses across the 4 5-minute time blocks</td>
</tr>
</tbody>
</table>
Figure 8.13 Letter Cancellation Test at 0-3, 6, 12, and 24 months post-TBI 101
Figure 8.14 Trails A Test at 0-3, 6, 12, and 24 months post-TBI 101
Figure 8.15 Trails B Test at 0-3, 6, 12, and 24 months post-TBI 102
Figure 8.16 Contingency Naming Test at 0-3, 6, 12, and 24 months post-TBI 103
Figure 9.1 Verbal Learning Test trials 1-4 at the acute (0-3) months stage 126
Figure 9.2 Verbal Learning Test trials 1-4 at the 6 monthly stage 127
Figure 9.3 Verbal Learning Test trials 1-4 at the 12 monthly stage 127
Figure 9.4 Verbal Learning Test trials 1-4 at the 24 monthly stage 128
Figure 9.5 Visual Learning Test trials 1-4 at the acute (0-3) months stage 128
Figure 9.6 Visual Learning Test trials 1-4 at the 6 monthly stage 129
Figure 9.7 Visual Learning Test trials 1-4 at the 12 monthly stage 129
Figure 9.8 Visual Learning Test trials 1-4 at the 24 monthly stage 130
Figure 10.1 Reading accuracy results at 0-3, 12, and 24 months post-TBI 143
Figure 10.2 Spelling results at 0-3, 12, and 24 months post-TBI 144
Figure 10.3 Arithmetic results at 0-3, 12, and 24 months post-TBI 144
Figure 10.4 Listening Comprehension results at 0-3, 12, and 24 months post-TBI 145
Figure 11.1 Predictors of educational and adaptive outcomes 152
Publications and communications

Data from this study has been published in the following peer reviewed journals:


Communications from this study:


Chapter 1: 
Introduction

While there is difficulty in establishing an accurate measure of the incidence of paediatric traumatic brain injury (TBI), some rough estimates have been made within particular community settings (Goldstein & Levin, 1987). Following trauma to the head, thousands of young lives are lost or permanent disability is sustained (Jennett, 1996; Mazurek, 1994). It has been reported that more than one million children in the United States suffer closed head-injuries per year and that one sixth of these are admitted to hospital (Eiben, et al. 1984). Other rough estimates indicate that 180 per 100,000 children sustain head injuries every year, with injuries most frequent in the birth to twenty four years age range (Kraus, 1985; Kraus, 1987). The most common type of TBI in children and adolescents is closed head injury (CHI), where the brain may oscillate within the skull and neuronal pathways may stretch or sever within the brain or brainstem (Davia & Vogel, 1995), leading to diverse sequelae.

Research investigating cognitive outcomes following paediatric TBI has found a number of deficits in the areas of intelligence, language skills, memory, new learning, educational ability and information processing skills, incorporating the areas of attentional ability and speed of processing (Chapman et al., 1992; Ewing-Cobbs, Miner, Fletcher, & Levin, 1989; Kriel, Kratch, & Paiser, 1989; Levin & Eisenberg, 1979; Marquardt, Stoll, & Sussman, 1988; Shaffer, Bijur, & Rutter, 1980).

Despite this high prevalence rate, much of the research in the area of closed head-injury has been aimed towards the adult population, the pattern of sequelae for this age group being outlined with some certainty in comparison to the paediatric population (Levine, 1988; Pruneti, Catini, & Barracchini-Muratorio, 1988). However, knowledge pertaining to the adult group is not reliably generalisable to the paediatric population. It has been stated that domestic falls and accidents with slow moving cars accounted for a large proportion of injuries in children, where-as
high speed vehicle accidents were mostly responsible for accidents in the young adult age range (Jennett & Teasdale (1981); Levin, Benton & Grossman (1982), Zimmerman, Larissa, & Bilaniuk, 1994). Despite the variability in cause of injury, the difference in mortality figures and recovery rates between adults and children are not yet fully understood. Anatomical and physiological features may explain some of the differences between the two age groups (Bruce, Schut, Bruno, Wood, & Sutton, 1978 cited in Levine, 1988). According to Jennett and Teasdale (1981) younger patients make a better recovery, independent of severity indicators such as pupil reactions and state of coma, although age effects were less apparent in severely injured patients. A number of features which may lead to different outcomes have been listed by Levin et al. (1982):

1. The child's skull has more flexibility in absorbing traumatic forces;
2. Intracranial haematomas are rarer in children;
3. When comparing children and adults with a grave neurological status, children seem to have a more favorable prognosis;
4. Anterograde and retrograde amnesia are less frequent in children under age nine years.

Other researchers suggest that outcome following TBI is less promising in the paediatric population. As stated by Pruneti et al. (1988), within the paediatric population the brain is still developing and its functions will, to some extent, modify with advancing age, therefore decreasing the predictability of outcome after childhood closed head-injury. Diffuse injury to the white matter of the brain may also occur as well as the stretching and shearing of nerve fibres which may also result in widespread damage, often caused by acceleration-deceleration effects (Adams, Graham Murray & Scott, 1981; Bruce et al., 1978 cited by Levine, 1988; Mattson & Levin, 1990). Since the brain is still developing, such diffuse damage may interrupt cerebral development, with areas such as neuronal myelination and frontal lobe maturation affected (Hudpeth & Pribram, 1990; Thatcher, 1991). These areas, which are vulnerable to damage following closed head injury, have been reported to be related to attention and information processing skills (Walsh, 1978).
Furthermore, while neuronal proliferation and synaptogenesis in the frontal cortex reaches a peak between 1-2 years of age, the frontal lobes and their functions continue to emerge throughout adolescence and young adulthood, suggesting that children may in fact experience deficits to already established skills as well as hampering those functions yet to emerge (Thatcher, 1991). These areas of the brain have been linked to the establishment of higher order skills such as information processing, planning and executive skills (Cicerone & Tupper, 1986; Milner & Petrides, 1984; Walsh, 1976). Therefore, the importance of research in the area of traumatic paediatric head injury is obvious, since damage during the early years (prior to full brain maturation) may affect established skills and limit new learning, exposing children with fewer established skills to cumulative deficits over time.

Focusing on attention, Mirsky, Anthony, Duncan, Ahearn, and Kellam (1991) have broken attention into several separate components. These components are known as sustained attention (capacity to maintain focus over time), selective attention (focused - ability to attend to a single stimulus while ignoring others; divided attention - the ability to attend to two or more stimuli simultaneously) and shift (the ability to change attentive focus in a flexible and adaptive manner). Such a model suggests that a deficit may be evident in any one of these components.

Deficits in attention and processing speed have major implications for the TBI child's adjustment and success in the classroom environment. Attending to information and retaining knowledge and skills presented in the classroom setting is the pre-requisite to learning development and this may be disrupted in children with a head-injury (Gulbrandsen, 1984). Therefore, knowledge concerning deficits in attention and information processing in the paediatric closed head-injured population is essential in the prevention of poor academic achievement and in the organisation of appropriate rehabilitation, therefore facilitating optimal development in the childhood years.

Monitoring the recovery of children who have sustained a closed head-injury provides an excellent model for investigating the cognitive and behavioural
consequences following such diffuse injury. While it has been established that, in the adult population, such injuries often lead to impairments in information processing skills (Ponsford & Kinsella, 1992), much less is known about the level of and recovery of these skills following TBI in childhood. By studying such injuries in children we can investigate the interaction between such injuries and the development of these skills over time.

The present study aims to investigate the recovery of skills in the cognitive, information processing, educational and adaptive domains, over a two year period, following paediatric head injury. Skills in these areas will be investigated at each time point, acute (0-3), 6, 12 and 24 months post-injury, as well as across time points in order to be able to plot the recovery of these skills over time. Of particular interest is the effect of poor information processing skills, particularly attention, on educational and adaptive outcomes over the two year period. Such findings will assist in the implementation of appropriate interventions for these children, so that primary difficulties can be addressed and secondary problems be prevented.
Chapter 2:

Mechanics of head injury

2.1 Primary and secondary effects of head injury:

For brain damage to occur in association with head trauma there must be relative motion between the skull and the brain. The effect on the brain depends partly on the magnitude of the force applied, the region of the skull that is affected most by the impact and whether or not the skull fractures (Amacher, 1988). More specifically, Begali (1987) defined the term traumatic head injury as a blow to the head, significant enough to produce some change in consciousness, and/or an associated neurological or behavioural dysfunction. The resulting brain damage results in physiological or structural change in the neural tissue of the brain to a pathological degree (Begali, 1987).

Specifically, closed head injuries lead to brain damage because of the initial compression of the head against an object and also because of the resultant acceleration-deceleration movement of the brain contents inside the skull. That is, the brain can move forward, backward and side-to-side (a rotational effect) within the skull. Acceleration injuries per se arise from the force of impact of a moving object on the child's slower moving or stationary head, for example, a child being hit by a baseball bat. With such a blow, the skull is set in motion (acceleration), but the brain, moving more slowly than the skull, then hits against the skull at the point where the force was exerted. Deceleration injuries occur when a stationary or slower moving object impacts on the moving head, such as when a child's head hits the dashboard of the car during an accident. In such a case, the skull is decelerated, the brain is still in motion and so it comes into contact with the skull (Fennell & Mickel, 1992; Hynd & Willis, 1988).

Both acceleration and deceleration effects can lead to damage to the brain as it impacts on the bony surface of the skull, both at the site of impact (coup) and opposite to the point of impact (contrecoup). In fact, injury is usually greater at the point of impact for deceleration injuries and more severe in the contrecoup region in
the case of acceleration injuries. The acceleration and deceleration effects can also stretch and tear nerve axons and blood vessels, therefore leading to diffuse axonal injury of the brainstem reticular formation (Fennell & Mickel, 1992; Hynd & Willis, 1988; Levin & Kraus, 1994). In fact, the rotational mechanisms emphasize the important concept of shearing strain which leads to multiple tearing of the neural elements throughout the deep areas of the brain. Furthermore, shearing strains are seen mostly along interfaces between grey and white matter, between brain and blood vessels and between the brain and the cerebrospinal fluid. Since the skull is rougher in some areas in comparison to others, shearing will be greater in some areas than others, resulting in a heterogeneous distribution of neuronal damage within the brain. This type of tissue damage frequently constitutes the limiting factor for the best possible recovery (Chorazy, 1985). Therefore, primary brain injury is due to mechanical damage that occurs at the time of injury as a result of contact between brain matter and the interior skull. Primary injury includes skull fractures, lacerations (tears in brain tissue usually related to depressed skull fractures) and contusions (bruising or microscopic haemorrhages) which these usually occur at the sight of impact or at contrecoup areas. Internal shearing forces can also lead to tearing and stretching of axons within white matter (Goldstein & Powers, 1994).

Adams, Graham, Murray, and Scott (1982), stated that diffuse axonal injury was defined as widespread damage to the axons in the white matter of the brain, and that this is a well-known consequence of non-missile head injury. It was also suggested that different degrees of damage may occur (severe to minor diffuse axonal injury), with lesser forms of white matter damage corresponding to what is known as concussion. Such damage may also account for the delayed recovery of cognitive functions after mild head injury. Much disruption of the nerve fibers may result in coma (Begali, 1987). These authors indicated that diffuse axonal injury occurs at the time of the head injury and that it is not a secondary event.

When reviewing the literature, it is evident that many secondary effects may occur following head trauma (Adelson & Kochanek, 1997) and the management of
these effects is essential after such trauma. Further, altered consciousness may be
described as a continuum of clinical syndromes that is evident after TBI, and which
may range from a momentary alteration or disruption in neurological functioning
(Gennarelli, 1987 cited in Fennell & Mickle, 1992) to prolonged coma (Hynd &
Willis, 1988). It was originally believed that structural damage did not occur with
mild injury, but more recently it has been stated that axonal changes may occur
following even minor head injury (Pang, 1985). In children a "childhood
concussion syndrome" has been described where, following closed head injury,
there is no loss of consciousness, but minutes to hours later, pallor, vomiting and
irritability develop and last approximately twenty-four hours (Shapiro, 1987).

Secondary effects of head injury include hypoxia, seizures, and oedema. Diffuse
cerebral swelling, due to an increase in the brain's water content (oedema) and
complicating haemorrhages, can compromise recovery. These haemorrhages
involve accumulations of blood in certain areas. Extradural haematomas are
situated between the skull and the dura, while subdural haematomas are localised
between the dura and the cerebral mantle. Elevated intracranial pressure (ICP) is
also common following paediatric head trauma. Within the skull there are four
intracranial constituents, namely, the brain, cerebro-spinal fluid, cerebral blood and
extracellular fluid, and an increase in any one of these areas, perhaps from the
formation of a collection of blood, fluid or pus not normally found inside the child's
head, will result in raised intracranial pressure, and so ICP is now monitored
routinely following TBI. (Amacher, 1987, Chorazy, 1985; Fennell & Mickle, 1992;
Hynd & Willis, 1988).

Secondary damage may also be due to neurochemical processes. Glutamate and
asparate, excitatory amino acids, are found at elevated levels following TBI. Ycates
(1999) reported that these elevated levels can disrupt cell function and cause cell
death, and they have also been found to correlate with anatomical pathology on
computed tomography (CT) scans (Baker, Moulton, MacMillan, & Sheddon, 1993).
In summary, following TBI, damage to the underlying brain tissue may range from mild to severe, depending on the nature of the injury. A common underlying factor in all cases of TBI seems to be shearing and tearing of nerve fibres which are a result of acceleration-deceleration effects. The extent of such damage to nerve fibres may be an important predictor of injury severity and subsequent outcome.

2.2 Determining the severity of head injury:

The questions that commonly arise when treating a child who has sustained a head-injury include: (1) What type of injury is it? (2) How can the injury be categorised and the level of severity established? (3) What are the predictors of long-term outcome?

While this review is interested in closed head injury, both penetrating and non-penetrating injuries will be briefly described in order to provide an overview of these types of injury and the corresponding effects. The two broad classes of injury, as mentioned above are penetrating and closed head injuries. It should be noted that trauma to the head does not always lead to brain damage. If the trauma is sufficient to cause central nervous system insults then brain injury will follow. A penetrating injury occurs when an object hits the head and causes the skull to fracture and move downward. Such an injury may cause the dura of the brain to tear, leading to laceration of the brain. A missile injury may cause damage as it passes through the dura, then lodging itself or passing through the brain tissue (perforating injury). A non-penetrating or closed head injury (as described fully in the previous section) is sometimes associated with a linear skull fracture, with the force of the trauma injuring the brain within the skull vault (Fletcher & Levin, 1988; Levin, Benton, & Grossman, 1982). It is in this latter type of brain injury that the primary effect is the shearing and stretching of nerve fibres.

When examining the literature available on TBI, and specifically on closed head injuries, it becomes evident that there exist different categorisations and diverse measurements of this type of head trauma. In recent years some consistency has
developed for measuring injury severity, although due to measurement error, a range of such measures are usually included in paediatric research, to optimise accurate diagnosis.

2.2.1 The Glasgow Coma Scale (GCS):

Consciousness, and the ability to respond appropriately to the environment, depend on the functioning of the centres in the ascending reticular formation and on the level of communication between these centres and the cerebral cortex. It follows that direct dysfunction or damage to the brainstem centres as well as a possible alteration in functioning due to diffuse subcortical white matter damage, all may cause loss of consciousness. Therefore, early assessment of the level of consciousness, is essential as it gives an indication of how the initial brain injury is in fact impacting on brain function (Miller, 1991).

The GCS (Teasdale & Jennett, 1974), is widely used as a measure of the depth and duration of impaired consciousness. Such a scale is important since many conditions result in coma or impaired consciousness, one such condition being dysfunction of the brain as seen following acute head injury. The GCS measures three aspects of behavior - eye opening, motor responses and verbal responses (See Table 2.1).

When using the GCS, the duration of coma (length of time the GCS is less than or equal to eight) is calculated by serial observations (usually 4 hourly), and consists of the time span in which there is no eye opening, an inability to obey commands and the absence of comprehensible speech. In terms of the categorisation of the depth of coma, the highest score possible is 15 and the lowest is 3, at which there is no eye opening, and no motor or verbal responses. The following criteria (Goldstein & Levin, 1992) is often used:

(a) A GCS of less than or equal to 8: severe TBI.
(b) A GCS of 9-12: moderate TBI.
(c) A GCS of 13-15: mild TBI.
Table 2.1.: GCS:

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Score</th>
</tr>
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<tbody>
<tr>
<td>Eye opening</td>
<td>Spontaneous</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>To command</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>To pain</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Nil</td>
<td>1</td>
</tr>
<tr>
<td>Motor Response</td>
<td>Obeys commands</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Localises pain</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Normal flexion</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Abnormal flexion</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Extension</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Nil</td>
<td>1</td>
</tr>
<tr>
<td>Verbal Response</td>
<td>Oriented</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Disoriented</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Words only</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Sounds only</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Nil</td>
<td>1</td>
</tr>
<tr>
<td>*Behavioral response</td>
<td>Smiles, oriented to sound, follows objects</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Consolable crying, inappropriate interactions</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Inconsistently consolable, moaning</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Inconsolable, restless, and irritable</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>No response</td>
<td>1</td>
</tr>
</tbody>
</table>

Behavioral response replaces Verbal Response for children of pre-school age and below (adapted from Teasdale & Jennett, 1974).

GCS is now routinely documented at the injury scene and during hospital admission, although there are a number of limitations: (i) reliability depends on the experience of the rater (Rowly & Fielding, 1991); (ii) if sedation or surgery is required the GCS is interrupted; (iii) there is some disagreement regarding the optimal time for measuring GCS to predict outcome. Most centres administer the
scale at regular intervals until the patient is conscious and responding (Fletcher, et al., 1995).

Marion and Carlier (1994), have also put forth similar precautions about the use of this scale. These authors state that contemporary pre-hospital treatment of patients with head trauma, often influences the reliability of the scale. In fact, it was suggested that different centres may not be arriving at a GCS in a comparative way. Pre-hospital intubation and sedation may also compromise the accuracy of the GCS taken in an emergency department. For patients who are intubated for an extended period of time, no GCS is available during this ‘artificial’ coma. Furthermore, different medical centres revealed much confusion as to who should assess the initial score, whether in particular cases the best or worst score should be recorded and when to test patients that had been medicated. Teasdale & Jennett (1974) had specified that the initial score should be assigned six hours post-injury, but with the changes in the treatment of severe TBI, many patients may already be undergoing surgery at this stage. Such observations suggest that the GCS is not without its problems and may be best utilised in conjunction with other measures such as post traumatic amnesia (PTA) and pupillary light response.

2.2.2 Post-traumatic amnesia (PTA):

The duration of PTA has also been argued to be a useful measure of the severity of diffuse brain damage (Rutter, Chadwick, & Shaffer, 1983). After the recovery of consciousness, there may follow a period of time during which recent events are not recalled reliably or accurately. The PTA period refers to a post-injury period of confusion and memory loss, after regaining consciousness, during which the patient is disoriented and unable to register day-to-day information, with older memories relatively resistant to cerebral insult. Therefore, the PTA is usually measured up to the point where memory for everyday ongoing events is continuous and reliable. Duration can be measured somewhat reliably as long as PTA lasts for an hour or more (High, Levin, & Gary, 1989). Begali (1992) defined the following criteria:

(a) A PTA of less than one hour: mild TBI.
(b) A PTA of 1-24 hours: moderate TBI.
(c) A PTA of more than 24 hours: severe TBI.

2.2.3 Pupillary light response:

Another measure of severity is the pupillary light response, which is an indicator of brain stem function. Unilateral loss of this function may be an indication of damage to the optic or oculomotor nerve on that side, but bilateral loss may be due to dysfunction to the pathway within the brainstem. Brainstem dysfunction in a patient with closed head injury often signifies a poor prognosis.

2.2.4 Radiological indicators of TBI severity:

Often skull fractures (linear and/or depressed) can be seen on an x-ray, however, such fractures are now better identified by computed tomography (CT), which also allows the clear identification of extra and intracerebral haematomas, and raised intracranial pressure (ICP) (Begali, 1987; Miller, 1991). While CT scans are used routinely following TBI, they are not sensitive to many pathologies which may occur. Computer images of the brain using magnetic resonance imaging (MRI) are more sensitive to microscopic shearing lesions, degenerative processes and specific white matter lesions. With the use of MRI scanning in particular, gradations in injury and distinctions between different forms of diffuse damage may be revealed (Wilson et al., 1988).

2.2.5 Conclusions:

Despite the usefulness of these measures and tools for categorising the severity of injury, it may be over-simplistic to categorise severity on the basis of one of these measures or tools alone, since a number of variables may be exerting a combined influence as well as interacting with other neurological lesions (Williams, Levin, & Eisenberg, 1990). Some researchers have devised their own criteria in order to describe mild, moderate and severe TBI, making it difficult to make comparisons between studies and to reach reliable conclusions in the paediatric TBI area. An example of such criteria is evident in a report by Curran (1993) where minor head injury was defined as loss of consciousness of 30 minutes or less, a GCS of 13-15 after thirty minutes and PTA not greater than 24 hours. In paediatric
populations, no single indicator has proven to be predictive in indicating severity of injury, therefore a combination of measures are used (Fletcher et al., 1995), a method also used in the current thesis.

2.3 Predictors of outcome following closed head injury:

All the measures used to establish the severity of TBI have also been used to predict outcomes following closed head injury:

2.3.1 GCS, PTA and Pupillary light response:

Much research has indicated a relationship between a low GCS and poor cognitive outcome (Goldstein & Levin, 1992; Hsiang, Yeung, Yu, & Poon, 1997; Levin, Goldstein, High, & Eisenberg, 1988). Alexandre et al. (1983) cited in Goldstein and Levin (1992) found that the highest GCS within twenty-four hours of admission was predictive of outcome two years post-injury. Of patients with minimal or no cognitive deficits, 80% had a GCS between 8-15. Seventy percent of patients with severe deficits had obtained scores of 3 or 4. Other researchers have focused on duration rather than depth of coma. Levin et al. (1988) reported that patients seen between 5 and 15 months post-injury and who had impairments in general intellectual functioning and memory, had more extended periods of impaired consciousness (median 18 days) than those performing adequately (median 1 day). Furthermore, Kinsella and colleagues (1997) found that change in placement from regular to special education at two years post-injury was best predicted by injury severity, as measured by the GCS and by neuropsychological performance at three months post-injury.

As well as a measure of the patient's ability to remember daily events (e.g.: name, place, time, date), PTA is also considered a predictor of long-term physical and mental recovery. Relationships have been reported (as with the GCS) between an increasing duration of PTA and residual cognitive, neurological and behavioural difficulties, however, discrepancies with regard to the usefulness and reliability of the measure, have been evident across studies (Carlsson, Svardsudd, & Welin, 1987 cited in Goldstein & Levin, 1992; Gronwall & Wrightson, 1981; Ruijs, Gabreels, &
Keyser, 1993; Rutter et al., 1981). Other researchers have found that in comatose patients, non-reactive pupils may be related to subsequent memory and intellectual deficits (Miller, 1981; Levin et al., 1988).

2.3.2 Radiological predictors - CT, PET, MRI

Research by Wilson and colleagues (1988) found that classifications derived from early (within 7 days) and late (within 21 days) MRI scanning were significantly correlated. However, when investigating neuropsychological outcome, it was stated that there existed a strong correlation with only the late MRI measure and basically no relationship with early MRI or early CT scans. It was concluded that lesions seen by late MRI scanning are important in terms of neuropsychological outcome. Other researchers have also found correlations between CT and MRI results with school problems, difficulties seen on a neuropsychological assessment and overall recovery (Levin et al., 1993; Ruijs Gabreels, & Thijssen, 1994; Stein, & Spettell, 1995).

2.3.3 Pre-morbid characteristics:

Non-injury factors may also be important when considering outcome from paediatric TBI. Pre-morbid levels of functioning may influence the level of recovery of a child. Haas, Cope, and Hall (1987) stated that per-morbid academic problems may be associated with head injuries as a result of impulsivity and distractibility, suggesting also that children with learning difficulties may in fact be risk-takers. Furthermore, Cattelani, Lombardi, Brianti, and Mazzuchi (1998) reported that subjects who suffer a severe closed head injury present with a higher pre-injury incidence of character disturbances than the normal population. Brown and associates (Brown, Chadwick, Shaffer, Rutter, & Traub, 1981) documented increased risk of psychiatric disorder post-TBI for children where such problems had been evident pre-injury. They reported that for those children without pre-existing problems, more than half were symptom free 12 months post-injury, however over half the children with some evidence of pre-injury behavioural or psychiatric disorder developed a clinically significant disorder within this time. However, Donders (1992) investigated the pre-morbid adjustment of 85 six to
sixteen year old children with TBI, via standardised rating forms completed by parents and teachers. It was found that less than 11% of the children appeared to have pre-morbid disturbances and so it did not appear that pre-morbid characteristics contributed to the incidence of trauma or to some of its sequelae.

2.3.4 Family functioning:

A number of studies have examined pre-injury family characteristics that may affect both the family and child’s functioning (cognitive, behavioural, emotionally) post-injury (Anderson, et al., in press; Kinsella, Ong, Murtagh, Prior, & Sawyer, 1999; Max, et al., 1998; Perlesz, Kinsella, & Crowe, 1999; Rivara, et al., 1995). It has been shown that for mild and moderately injured children there are few declines in overall functioning one year post-injury. The severely injured children had the most dramatic early declines and improved only slightly between three months and one year, with older children from poorly functioning families deteriorating in the same period. It was concluded that strong pre-injury family functioning, a high level of cohesiveness, positive family relationships and a low level of control are predictive of good functioning (global, adaptive and social) one year following traumatic brain injury (Rivara et al., 1993). Similarly, other researchers report that pre-injury family functioning is related to a child’s risk of developing a psychopathology post-injury and that furthermore, this risk is also related to post-injury family functioning, stressing that both the pre and post family environments contribute to a child’s status and recovery post injury (Max et al., 1998). Further support of pre-injury factors was evident when it was reported that poor academic and cognitive outcomes one year post-injury were associated with injury severity, pre-injury family and child functioning, and post-injury environment, with variation in behavioural outcomes explained by pre-injury child or family factors (Rivara et al., 1994; Taylor, et al., 1999). Yeates and colleagues (1997) found that measures of the pre-injury family environment consistently predicted the level of cognitive and behavioural functioning at 12 months post-injury and the rate of intra-individual change during the 12 month follow-up period, even after taking into account injury severity.
2.3.5 Age at injury:

At least three different points of view have been offered with regard to age at injury. First, that children show greater vulnerability and less recovery of function than adults, second, that children show greater behavioural sparing and recovery than adults and lastly, that the effects of brain trauma on the paediatric population will depend on the actual age of the child, and on the ability of the immature brain to develop new strategies for acquired areas of deficiency (Fletcher & Levin, 1988; Rutter, Chadwick, & Shaffer, 1983; Taylor & Alden, 1997).

When investigating children and adults, it is difficult to compare cognitive outcomes because the aetiology of the injury and the specific timing of the injury may change the cause of a child's future growth and development (Isaacson, 1975 cited in Segalowitz & Brown, 1991). As skills show different developmental trajectories, patients injured at different ages will show a different recovery of specific skills. For example, younger children tend to recover writing skills much more slowly than adolescents (Ewing-Cobbs, Levin, Eisenberg, & Fletcher, 1987).

While the differences in recovery rates for children of diverse ages, as well as adults, are not fully understood, a number of researchers have investigated long-term outcomes in terms of age at injury. Klonoff, Low, and Clark (1977) carried out a research study comprising a group of children five years following a closed head injury. The children were divided into two groups (less than 9 years, n=78 and older than 9, n=39). Children were graded in terms of severity on a five point rating scale ranging from minor (no loss of consciousness; no concussion) to severe (loss of consciousness for more than thirty minutes; skull fracture; other sequelae). It was concluded that head injured children exhibited impaired neuropsychological performance in comparison to controls, but the deficits were more or less equally distributed between the older and younger groups. A subsection of this sample of children were followed-up 23 years post-injury (Klonoff, Clark, & Klonoff, 1993), where it was stated that the severity of the head injury was found to be the primary contributing factor in the reconstitution process. Similarly, Vignolo (1980) found no relationship between outcome and age at injury.
However, other researchers have argued that injuries sustained in early childhood are associated with poorer outcome when compared to children whose injuries were sustained later in childhood (Anderson et al., 1997; Anderson et al., 2000; Anderson & Moore, 1995; Didus et al., 1999). In fact, these researchers have argued that children injured in late childhood showed recovery consistent with that showed in adult injury, where-as those injured in early childhood failed to exhibit the expected acute recovery pattern and maintained a stable performance from 4 months to two years post-injury. Kriel, Kratch, and Panser (1989) investigated the outcome of 97 children with severe closed head injury. Children were divided into two groups, those younger than six and those six and above. It was found that children of age six and above had better cognitive and motor outcomes than the younger patients, with abused children (those below six years) facing the worst outcome. Similarly, Thompson et al. (1994) also found that younger children with severe injuries showed slower growth on visuo-spatial and motor tasks than did older children of similar severity, supporting a hypothesis of increased vulnerability of emerging skills in young children.

2.3.6 Time since injury:

It is now well established that the cognitive consequences of head trauma include deficits in general intellectual functioning, as well as poor memory, language and attentional skills (Golstein & Levin, 1992). However, performance in these areas will be affected by the amount of time that has lapsed since the injury, recovery of skills post-injury and expected developmental gains.

A number of studies (Chadwick, Rutter, Brown, Shaffer, & Traub, 1981; Dikeman, Machamer, Tempkin, & McLean; 1990; Klonoff, Low, & Clark, 1977) have investigated performance on a variety of cognitive tasks, at different time points following head trauma. There is general consensus that there is an improvement in all functions in the first year, with recovery in the second year more dependent on the severity of injury and type of function, and with further recovery possible in the future. Therefore, it would be expected that differences between children who sustained mild, moderate or severe injuries would be most pronounced
in the acute stage, before recovery takes place. However, it has also been reported that a group of mildly injured children, while performing comparably to a non-injured group in the acute stage post-injury, presented with specific problems at six months post-injury (Wrightson, McGinn, & Gronwall, 1995). Such findings suggest that not all deficits may be evident soon after an injury, but may present at a later time when a specific skill has not developed appropriately.

The complexity of attempting to predict outcome following an injury in childhood is evident. An accurate prediction of outcome will be dependent on the stage in the recovery process (time since injury) when skills are assessed, and the age of the child both at injury and at the time of the assessment, so that developmental issues can be addressed. It is important that longitudinal research is conducted to monitor recovery and so establish which predictors are most useful.

2.3.7 Conclusions:

Overall, there are many factors as those described above, which help to explain why there is variability in recovery from injuries that appear similar. However, the diverse conclusions reached by the many studies (often due to methodological differences) often makes interpretation of results difficult. As stated by Dennis (1985), it is likely that the complex interplay of condition, locus of lesion, and treatment variables, rather than a single factor interpretation, is the better predictor of outcome following paediatric head trauma.
Chapter 3:

Outcomes following TBI:

3.1: Introduction

The current chapter is an overview of research investigating outcomes following paediatric TBI in a number of areas including intellectual, language, memory, executive, educational and psychosocial areas. This chapter has been included to provide an indication of the literature available, with some areas highly researched, such as intellectual ability, and others poorly investigated, such as educational outcomes. The information in many areas is brief, as it is discussed in more detail in the following chapters. Therefore, while the main focus of this thesis is in the area of attention, it is important to investigate the literature in these areas in order to establish a general understanding of the outcomes following paediatric TBI. Furthermore, attentional impairment may play a role in the difficulties seen in many domains as it may underlie and impinge on performance on many tasks.

3.1.1: Mild, moderate and severe TBI:

A search of the literature on mild head injury reveals that only a limited number of studies have been undertaken despite the high prevalence of such an injury. Furthermore, the continuing inconsistency surrounding the definition of mild TBI is further complicated by the debate regarding the presence or absence of residual deficits following such a trauma (Levin, 1988).

A number of studies have reported that mild head-injury is not associated with an increased risk for long-term psychiatric or cognitive deficits. (Asarnow et al., 1995; Bijur, Haslam & Golding, 1989; Brown, Chadwick, Shaffer, Rutter, & Traub, 1981; Chadwick, Rutter, Brown, Shaffer, & Traub, 1981; Fay et al., 1993; Mitchell et al., 1994), possibly due to an absence of serious underlying brain pathology. On this basis, the mild TBI group is important to investigate as they present a qualitatively different group to those children who sustained a moderate or severe TBI, where in the latter TBI groups the deficits appear long-term rather than transient in nature, and brain damage is clearly documented.
Conversely, a number of studies have found significant long-term effects related to mild TBI. Impairments have been reported in the areas of reading skills (Gronwall, 1991; Gronwall, Wrightson, & McGinn, 1997; Wrightson, McGinn, & Gronwall, 1995); problem-solving and reasoning (Bassett & Slater, 1990; Gulbrandsen, 1983); real-world functioning (Polissar et al., 1994); verbal fluency and story recall (Anderson et al., in press); neurobehavioural functioning (Segalowitz & Lawson, 1995); hyperactivity (Segalowitz & Brown, 1991). As also stressed by Ommaya and Gennarelli (1974) and Oppenheimer (1968) both cited in Bassett and Slater (1991), even in mild TBI, there is stretching and shearing of neuronal fibres and that areas of the brain next to skull irregularities, such as the frontal and temporal lobes, are most susceptible to injury, suggesting some degree of impairment in function.

A further critical issue is that of pre-morbid functioning. Chadwick, Rutter, Brown, Shaffer, and Traub (1988) believed that the mild head injury cases that they investigated had pre-existing deficits. Since there was an absence of recovery phase following the injury, the authors concluded that the initial deficit was not due to acute brain damage. Similarly, Ponsford et al. (1997) reported that pre-morbid level of functioning, in the learning and behavioural areas, is a strong predictor of outcome post-injury following mild TBI. Conversely, Pelco, Sawyer, Duffield, Prior, and Kinsella (1992) did not find any evidence suggesting that emotional and behavioural problems were elevated in a consecutive series of mild or severe head injury cases in comparison to children in the community.

Therefore, it is clear that the findings related to mild TBI are controversial, and that positive and negative outcomes have been reported in injuries sustained during pre-school and primary school years, depending on the methodology of the study. While many of these studies employed the traditional measures of severity, one reason for discrepancies may be the variability of injury. While the GCS is the best measure available it does not accurately assess the degree of brain damage. Many children who do not have lowered GCS may nevertheless experience injuries associated with significant brain damage (e.g. children with focal injuries that do not
involve the brainstem). Some researchers (Brown, Fann, & Grant, 1994) have also reported MRI abnormalities following mild TBI, while others do not, again possibly reflecting the different definition of mild head injured employed in different studies. As summed by Parker (1994), following mild head injury, several years may pass before dysfunction or deviation from the expected level of development is evident, suggesting a need to follow-up children over time.

Unlike the uncertainty about the absence or presence of long-term effects following mild TBI, the literature investigating moderate-severe TBI, not surprisingly, consistently cites long-term intellectual, behavioural and adaptive sequelae for this group, with most recovery within the first year post-injury, and less continual recovery in the second and third years (Brink, Garrett, Hale, Woo-Sam, & Nickel, 1970; Chadwick, Rutter, Shaffer, & Shrout 1981; Costeff, Groswasser, & Goldstein, 1990; Costeff, Groswasser, Landman, & Brenner, 1985; Dikeman, Machamer, Temkin, & McLean, 1990; Heiskainen & Kaste, 1994). Further-more, severe head injury, especially during the pre-school age, often leads to poor outcomes both educationally and in the workforce (Koskineniemi, Kyykka, Nybo, & Jarho 1995; Fletcher, et al., 1995; Massagli, et al, 1995).

Of interest is a study which reflects the issue of pre-morbid functioning. Haas, Cope, and Hall (1987), stated that up to 50% of a sample of 80 severely injured children (defined as coma longer than 6 hours) had poor prior academic performance as defined by diagnosis of learning disability, multiple failed subjects or school drop-out, suggesting that pre-morbid functioning was an important predictor of outcome.

Rather than focusing on one level of severity, many researchers have compared children of differing severity levels in order to ascertain the differences in outcome, if any, between those afflicted with a mild, moderate or severe head injury. The literature in this section is again difficult to generalise due to differing definitions and methodology between studies and interpretations of results (Beers, 1992).
Researchers generally report that despite the recovery observed, children with severe injuries continued to perform below the mild-moderate group on all measures such as intelligence (Chadwick, Rutter, Brown, Shaffer, & Traub, 1981; Ewing-Cobbs, Miner, Fletcher, & Levin, 1989); motor ability, expressive and receptive language (Ewing-Cobbs, Miner, Fletcher, & Levin, 1989); performance IQ, motor speed and coordination, tactile/spatial functioning and verbal fluency (Knights et al., 1991; Winogron, Knights, & Bawden, 1984); speed of processing, memory, attention and behaviour Ewing-Cobbs, Fletcher, & Levin, 1986; Fay & Janesbeski, 1986).

A series of investigations (Fay et al., 1994; Jaffe et al., 1992; Jaffe et al., 1993; Jaffe, Polissar, Fay, & Liao, 1995) were conducted on the same sample of mild moderate and severe TBI children, aged 6-15 years at the time of injury, at three weeks, one year and three years post-injury. Similar results were reported with means of the moderate and severe children falling within the 'normal' range, with strong improvement during the year, however, their scores were substantially below those of the matched controls on many measures. There was negligible change in the following two years and at three years post, given the 'plateauing' of recovery. A general conclusion is that following severe TBI, it is unlikely that children who had sustained moderate or severe injuries would achieve parity with peers (Ewing-Cobbs, 1997).

However, many of these studies comparing children with different severity levels, further strengthen the belief that it is not possible to reliably compare studies in the area of paediatric head-injury. There is still a need for concrete definitions of severity, the need for similar methodologies and the need to take into account pre-morbid characteristics, post-injury environment, interventions received and the developmental level of the child prior to the injury (Fletcher, Ewing-Cobbs, Francis, & Levin, 1995; Lazar & Menaldino, 1995).
3.2 Language outcomes:

While there has been much attempt to explore the cognitive outcomes following TBI (mild to severe) in the paediatric population, the amount of research looking into the language sequelae following head trauma in this young population has been quite limited. However, research has reported difficulties in a number of language areas including subtle language processing difficulties (Ewing-Cobbs, Fletcher, Levin, & Landry, 1985 cited in Ewing-Cobbs & Fletcher, 1987); expressive and receptive difficulties (Morse et al., 1999); naming ability, expressive skills and written language (Campbell & Dollaghan, 1990; Ewing-Cobbs, Levin, Eisenberg & Fletcher, 1987; Hallett, 1997). Written language develops most rapidly during the 6-8 years age bracket (Cribson & Levin, 1985 cited in Ewing-Cobbs et al., 1987) and so findings suggest that emerging written-language skills are prone to disruption, since brain injury may affect the acquisition of these new skills in the young age bracket, possibly confounded by psychomotor slowing (Knights et al., 1991; Winogron, Knights, & Bawden, 1984).

Pragmatics and higher order processing skills have also been investigated following paediatric TBI (Jordan, Murdoch, & Buttsworth, 1991). The results indicated that the head injured children did not perform differently on a spontaneous story production task when compared to age matched controls. In addition, there was no significant difference between the mild and severe groups on any of the narrative measures assessed. It was concluded by these researchers that discourse in a conversational setting should be observed in order to evaluate whether difficulties may then become evident.

Conversely, other studies of narrative discourse have found deficits at least one year post-injury (Chapman et al., 1992), with specific areas impaired including disruption in story structure (Botvin & Sutton-Smith, 1977 cited in Chapman et al., 1992); dysfluency (Biddle, McCabe, & Bliss, 1996); poor knowledge of ambiguous words in context and limited understanding of metaphoric expressions (Dennis &
Barnes, 1990), difficulties with syntax, semantics and pragmatics (Didus, Anderson, & Catroppa, 1999; Jordan & Murdoch, 1994).

It has also been suggested that that severe TBI in childhood results in a generalised decline in cognitive performance which then affects linguistic skills across all domains, rather than a specific linguistic impairment in a single linguistic domain (Jordan & Ashton, 1996; Jordan & Murdoch, 1994). Furthermore, that focal damage to the dominant hemisphere will result in specific speech and language deficits (Marquardt, Stoll, & Sussman, 1988). It was further concluded that following closed head injury, the primary features of diffuse damage are early recovery of language form but residual impairment is evident in the ability to use language for effective social interaction. Therefore, while the most documented deficit following head in trauma is word retrieval impairment, of more importance is the fact that patients may be poor communicators, with a disturbance in the use of pragmatics, a lack of cohesion in discourse and difficulties at the level of cognitive organisation (Capuso & Levin, 1992, Ewing-Cobbs, Brookshire, Scott, & Fletcher, 1998; Goldstein & Levin, 1992; Marquardt et al., 1988). As summed by Dennis (1989), early brain damage has shown to affect language developmentally, and so in some instances the type and extent of language difficulties are not apparent for some years post-injury, again high-lighting the need for longitudinal follow-up following paediatric TBI.

Comparison of language outcomes across studies is difficult due to differences in language measures, in definitions of injury severity, in subject selection criteria and in injury-test intervals (Ewing-Cobbs et al., 1987), however, it does become evident that some types of deficits do exist, such as object naming and discourse. There is currently no full understanding of how early brain damage influences existing language functions and the course of future language acquisition. Deficits may be related to variables such as site of injury, age of subject or cognitive level. In fact, Chapman et al. (1992) stated that one possible mechanism underlying discourse deficits (as well as other areas of difficulty) may in fact be a memory deficit. It may be suggested that perhaps early brain damage affects information
processing skills such as attention and memory, which then go on to affect other higher level skills such as language.

3.3: Memory outcomes:

Although the capacity to consolidate and retrieve information is obviously crucial for academic competence and success, relatively few studies have evaluated post-traumatic memory functions (Ewing-Cobbs & Fletcher, 1987). The prominence of memory deficits across the spectrum of severity reflects the vulnerability of the temporal lobes to contusions and haematomas (Levin et al., 1987). Furthermore, the initial GCS, duration of consciousness and integrity of ocular responses are strongly related to long-term memory problems (Dikeman, Temkin, McLean Wyler, & Machamer, 1987; Vilkki, Poropudas, & Servo, 1988 cited in Goldstein & Levin, 1992;). It was further indicated by Levin, Eisenberg and Gary (1991) cited in Levin and Eisenberg (1991) that the deficits seen in memory functioning depend on the type of material used (auditory versus visual) and on the procedure (recall versus recognition).

Specific research papers in the paediatric area have reported deficits, more commonly following severe TBI (Levin, Eisenberg, Wigg, & Kobayashi, 1982; Max et al., 1999), in a number of areas such as verbal memory and continuous recognition memory Levin & Eisenberg, 1979; visual recognition memory (Levin et al., 1988); learning and delayed recall (Yeates, Blumenstein, Patterson, & Delis, 1995); visual recall for geometric figures (Donders, 1993); inefficient rehearsal strategies, poor monitoring, limited metamemory and encoding (Farmer, et al., 1999; Harris, 1996; Roman, et al., 1998).

Taking a developmental perspective, (Levin et al., 1988), similar to previous studies, found a memory deficit at least one year following a severe head injury. Impairment of visual recognition memory was related to injury severity. Severity was also related to residual verbal memory deficit in the adolescent group but the results pertaining to the younger age groups were not that clear. It was stated that
visual recognition memory is established early in life and so was prone to disruption across all groups, however, that verbal memory skills are undergoing development in the adolescent but yet to emerge in the younger groups and so the effects, at this stage, were only evident in the adolescent group. Younger children may show verbal memory difficulties when these strategies would normally develop, that is, the effects may not be obvious until the relevant skills would normally appear. Overall, the three studies that have been outlined (Levin et al., 1979; Levin et al., 1982 and Levin et al., 1988) have all reported similar findings.

When considering the other end of the continuum, an adult sample, Levin, Goldstein, High, and Eisenberg (1988), examined 87 survivors of moderate to severe closed head injuries. It was found that almost one quarter of those tested expressed defective memory on both auditory and pictorial measures, while all performed within the "Average" range on the Wechsler Verbal and Performance Quotients suggesting that factors other than Intelligence Quotients affected memory function. Gronwall & Wrightson (1981) who also investigated a sample of adult patients with closed head injuries and memory impairments, reported that attention and concentration factors may have influenced the results. It has also been stated that a verbal memory deficit is one of the neurobehavioural sequelae that is strongly related to unemployment seven years after a head injury (Levin, 1989). It may be suggested by this series of reports that memory deficits are apparent soon after TBI and deficits may well persist into adulthood, therefore making it essential to investigate possible factors, other than injury severity, which may be impinging on memory functioning.

In an attempt to interpret results, Levin (1989) has described different aspects of memory functioning. It was suggested that increased interference and more rapid decay of memory (Squire, 1981 cited in Levin, 1989) may contribute to impaired long-term memory following severe TBI. Furthermore, some patients may experience material-specific deficits while others difficulties of a more generalised nature. It was also put forward that head injury patients may require greater effort to process information that is processed "automatically" by "normal" children.
Therefore, if energy is given to areas that "normal' children process "automatically", then there may be less capacity for encoding the material that is to be recalled and learned (Hirst, 1982 cited in Levin, 1989). This may all be related to diffuse axonal injury which produces cortical-subcortical disconnection and degeneration of cerebral white matter (Ommaya & Gennarelli, 1974 cited in Levin, 1989).

3.4: Executive functioning outcomes:

In a review by Welsh and Pennington (1988), it was stated that "executive functioning" can serve as a conceptual framework for investigating pre-frontal function in developing children. Furthermore, that frontally mediated functions emerge in the first year of life and continue to develop until puberty and perhaps beyond, with the specific time at which the frontal lobes actually begin to exert executive functioning skills being contradictory. Executive function has been defined as the overall ability to maintain an appropriate problem-solving set for attainment of a future goal. The set includes one or more of the following: (1) impulse control; (2) a strategic plan of action sequences; (3) organised search and; (4) flexibility of thought and action (Weyandt & Willis, 1994; Ylvisaker and Szekeres, 1989).

It has been reported that lack of executive control over cognitive functions and behaviour is a major obstacle for severely injured subjects (Goldenberg, Oder, Spatt, & Prodrcka 1992). The frontal area is also believed to mediate the highest forms of mental activity such as creativity, abstract reasoning and conceptual abilities (Nelson, 1976; Novia & Ardila, 1987 cited in Mattson & Levin, 1990; Milner & Petrides, 1984; Shallice & Evin, 1978;) and so deficits may be seen in formal activities (E.g. tasks requiring attentional skills, mental flexibility) as well as in everyday living skills.

Despite the number of deficits which may occur if the frontal lobes are damaged (Goldstein & Levin, 1992; Stabulum, Mogentale, & Umilta, 1996), only a very limited number of studies have investigated behavioural and/or cognitive outcomes following closed head injury and frontal lobe damage. Furthermore, actual deficits
may be caused directly by the damage to the frontal lobes or by the disruption of connections between the frontal lobes and other brain areas. Therefore, personality changes, impairments in cognitive functioning and attentional disturbances may be linked to the frontal lobes following closed head injury (Mattson & Levin, 1990). Ylvisaker and Feeney (1995) stated that adequate performance on tests of intelligence or language, combined with impaired performance on everyday or ‘real-life’ tasks is often a hallmark of frontal lobe injury in children.

Of the few studies investigating executive functioning following childhood TBI, Dennis, Barnes, Wilkinson, and Humphreys (1996), investigated the metacognitive skills of knowledge appraisal and knowledge management in a group of head injured children and a group of normally developing children. Appraisal skills involved fact based knowledge gained from experience and stored in long-term memory, whereas management skills involved maintaining and revising ongoing performance and making judgments where necessary. It was found that head injured children and young, normally developing children performed poorly in both the areas of appraisal and management. While the young normally developing children were found to have a limited knowledge base, this was not so for the head injured children who presented with a difficulty in sustaining the application of appraisal skills. That is, even with a relevant information base, head injured children do not always engage metacognitive processes.

More recently, a group of 151 head injured children were compared to 89 controls, with a subsection of the children seen longitudinally at 3 months and then 36 months (Levin et al., 1997). Children were assessed on measures purported to tap executive functions, such as the Twenty Questions Test, the Tower of London and the Wisconsin Card Sorting Test. It was found that severity of injury affected performance on all three measures of executive functioning, with MRI findings increasing the prediction of performance on the Tower Of London and the Wisconsin card Sorting Test. These authors concluded that caution must be taken as impaired performance on these tests may be attributable to group differences on tests on intellectual ability and attentional skills.
Wilkins, Shallice, & McCarthy (1987) have linked frontal lesions to attentional capacity, however, there are only a limited amount of studies looking at attentional ability following such a specific lesion. In this study by Wilkins et al. (1987), sixty-nine adult patients were undergoing neocortical removals for epilepsy. It was concluded that attentional deficits are specifically linked to frontal lobe lesions. Furthermore, the frontal lobes are particularly susceptible to parenchymal and extra-paranchymal lesions as a result of TBI. They are highly susceptible to the effects of closed head injury as induced by acceleration-deceleration accidents (Capruso and Levin, 1992). Therefore, the effects following frontal lobe damage, such as deficits in attention, planning and organisation, need to be examined more precisely following paediatric head trauma.

3.5 Psychosocial outcomes:

While not the central focus of the present study, the area of psychosocial function is critical to the overall recovery and quality of life of the child post-TBI. A number of studies have stressed the importance of investigating psychosocial factors which may become problematic following TBI. A three factor model was proposed by Pepping and Roueche (1991) where the important factors to be considered were the child's pre-injury assets and liabilities, the nature and the severity of the long-term residual effects and reaction to difficulties. Some authors have reported that head injured children display more problem behaviours, are less socially competent and show less adaptive living skills compared to sibling controls (Asarnow, Satz, Light, Lewis, & Neumann, 1991; Greenspan & MacKenzie, 1994; Papero, Prigatano, Snyder, & Johnson, 1993; Perrott, Taylor, & Montes, 1991).

Fletcher, Ewing-Cobbs, Miner, Levin, and Eisenberg (1990) found that children who sustained severe head injuries displayed a decline in adaptive functioning, had more school problems and engaged in less social activities, whereas those with mild-moderate injuries did not deviate from average levels of functioning. Perhaps this decline in social activities may be linked to head injured children's inability to interpret emotions and social cues often making friendships difficult to maintain.
(Pettersen, 1991). Still investigating the severely injured children, Brown, Chadwick, Shaffer, Rutter, and Traub (1981) reported that there was also a marked increase in psychiatric disorders in this group of children (seen by a dose-response relationship). As concluded by Livingstone and McCabe (1990), psychosocial recovery lags behind physical recovery and in turn it affects the individual’s performance at home, school and in the community (Costner, Haley, & Baryza, 1993; Sarapata, Herrmann, Johnson, & Aycock, 1998), soon after the injury and in the long-term. This finding stressed the need for further research in this area so that children at risk can be identified, remediation offered and the suggested link between post-injury psychosocial functioning and its effect on cognitive recovery can be investigated.

3.6: Educational outcomes:

The ultimate goal of much research following paediatric TBI is to define residual impairments in neuropsychological functioning, and to determine whether these difficulties compromise functional outcomes. An outcome of specific interest is a child’s achievement at school, post-injury, particularly in the areas of reading, spelling, comprehension and arithmetic. Despite the importance of information in this area, only a few studies have investigated outcomes in this area.

Milton, Scaglione, Flanagan, Con, and Rudnick (1991), stated that the classroom and the demands of academic activities requires that each student is able to deal with cognitive, communicative, visual-spatial, physical and psychosocial challenges. Of most importance, success in the classroom setting requires the student to integrate and to remember (or be able to retrieve when necessary) large amounts of information and to be able to use attentional capacity efficiently. These authors report that the use of standardised tests, as well as a functional evaluation as important issues when formulating an appropriate educational plan in the classroom. This viewpoint was also put forth by Goldstein and Levin (1985), Johnson (1992) Taylor and Schatschneider (1992), who challenged the practice of
using IQ criteria for clinical diagnosis, stating that more fine-grained tests tapping problem-solving and subtle information processing should be utilised.

Neuropsychological studies following TBI injury have not adequately reported outcomes in terms of specific scholastic deficiencies (Berger-Gross & Shackelford, 1985). In a study by Donders (1994), the academic placement of 87 children aged between 6-16 years, who had sustained a brain injury was discussed. It was reported that forty-five children were in full time regular school, twenty-one children needed special education support and twenty-one children were enrolled in special education classes. Factors which appeared to be important with regard to school placement were cerebral oedema and skull fracture.

Telzrow (1989) provided a brief review of the educational outcome of children who had sustained head injuries. Longitudinal outcome studies of such children have often found that the injury has a profound impact on the educational adjustment of these children when returning to school. Difficulties have been found in the areas of motor ability, intellectual functioning, language skills, learning (the acquisition of new information), memory, concentration and attention deficits (Chadwick, Rutter, Brown, Shaffer, & Traub, 1981; Ewing-Cobbs et al.,1985; Levin, Benton, & Grossman, 1982; Stover & Zeiger, 1976 cited in Telzrow, 1987). It then follows logically that neuropsychological and cognitive deficits will then affect educational performance (Carney & Gerring, 1990), and restrict chances of scholastic success (Stratton and Gregory, 1994).

Telzrow (1987) felt that there were a number of additional factors that determined successful re-entry to school. These factors included the lack of appropriate programs catering especially for children who had sustained a TBI, the extended vacation time (e.g.: summer holidays) and the variable and conflicting demands of diverse teachers and different rooms (especially for children who have difficulty sorting and prioritizing environmental stimuli). Also outlined were necessary characteristics for head injured children and these included a maximally
controlled environment, low teacher-pupil ratio, an intensive and repetitive program, fading and shadowing exercises and home-school liaison.

Shaffer, Bijur, Chadwick, and Rutter (1980) researched the impact of TBI on later reading skills in a group of school aged children, aged between 7-12 years. It was found that one third of the children had a reading age at least 24 months behind their chronological age. It has been suggested that the effect of a head injury on scholastic achievement may be is mediated through a lowering of general intelligence (Chadwick, Rutter, Thompson, & Shaffer, 1980; Shaffer et al., 1980; Slater & Kohr, 1989; Rivera et al., (1994).

Alternatively, Berger-Gross and Shackleford (1985) reported on the performance of 15 children who sustained a closed head injury with a mean coma of nine days. These children were seen 3-6 months and then one year post-injury. It was found that arithmetic was poorer than both reading or spelling. Difficulties were found to persist after the children’s IQ level had improved. Another comparable finding was also reported where children with moderate to severe injuries showed problems in reading and spelling, with little improvement after six months of schooling (Kinsella, Sawyer, Bryan, & Anderson, 1994). As summarised by Obrzut and Hynd (1987), in most cases complete recovery from severe head injury does not occur, and there is often a reduced capacity to function at pre-morbid levels.

Barnes, Dennis, and Wilkinson (1999) investigated reading skills following childhood TBI, focusing on a developmental perspective. It was suggested that if head injury affects the acquisition of skills not yet acquired, then younger children (before formal reading instruction), should be at the highest risk for difficulties in acquiring the basics of reading, such as word decoding. For children injured in middle childhood, where comprehension skills (e.g.: inferencing) are still being acquired, the risk may be greatest for reading comprehension, where decoding accuracy and decoding speed may be compromised. After investigation, these authors then found that children who sustained injuries during pre-school years or in
early primary grades, were most at risk for difficulties in both decoding and comprehension skills, where-as children between the ages of 6.5 and 9 years at the time of injury, performed better than younger children, but more poorly than an older group of children. Therefore, these authors revealed both the importance of developmental issues and injury factors in determining outcome in the reading and comprehension areas.

3.6.1 Conclusions

It is clear that studies directly investigating head injuries and functional outcome, in the paediatric population, are minimal. It has been quoted that the areas often affected following a brain injury include social judgment, perception, abstract reasoning and most importantly, attentional control (Goldstein & Levin, 1985; Taylor & Schatschneider, 1992). A subtle but common theme that becomes evident in a number of sections of the literature review is that cognitive, memory and executive skills may be affected by an underlying attentional difficulty, and so it may be stipulated that this same deficit may be underlying educational deficits.

It follows that an area that needs to be researched is attentional skills and their impact on educational outcome following paediatric head injury. Attention is an essential first step in a model of information processing, and so may be a critical factor underlying observed deficits, therefore it is essential to ascertain the degree of attentional deficits following head trauma so that the link between attention and other skills is better understood and so that rehabilitation services can be more meaningful and focused in their approach. To date rehabilitation programs have stressed the importance of working with the family, and have focused on improving areas such as cognitive and communicative skills, organisational skills, metamemory, executive functioning, memory and attention skills, however results from these programs have been quite variable, perhaps suggesting that the specific underlying difficulty is not being treated. An important finding was reported by Kelly, Best, and Kirk (1989) where measures of pre-frontal functions distinguished between reading disabled and non disabled boys. The reading disabled boys had difficulties with processes including selective attention, sustained attention and
inhibition of routinised responses. This stresses the need for specific research, such as the investigation such as the recovery of attentional skills and the impact of attentional difficulties in the areas of memory, learning and in the acquisition and maintenance of educational skills following head injury (Blosser & De Pompei, 1989; Gummow, Miller & Dustman, 1983; Miller, 1992; Ponsford & Kinsella, 1988; Wilson, 1992; Ylvisaker, Szekeres, & Hartwick, 1992).
Chapter 4: Models and theories of attention

4.1: Introduction

Since attention is the foundation of most cognitive and neuropsychological functions, it is important to consider its role on outcome measures following TBI. There is a strong relationship between attentional functioning and the effectiveness and proficiency of memory, perceptual, problem-solving and motor systems. Therefore, attention has an important impact through its influence on cognitive and neuropsychological systems which in turn influence adaptive, social and academic functioning (Cooley & Morris, 1990).

Information processing models provide a means for investigating and understanding attentional and cognitive development (Siegler, 1983b cited in Flavell, 1985). In such an approach, the mind, like a computer, manipulates and processes incoming or stored information. Processing can take place in a number of steps such as encoding, decoding, comparing, combining, storing and retrieving information (Flavell, 1985). This information processing approach has a main objective and that is to explain what the cognitive system does when dealing with a task or problem. The ideal goal of such an approach is to achieve a model of cognitive processing that is precisely specified, explicit and detailed.

Most importantly, if attention is deficient, then information that needs to be processed may not be stored at all and so is unavailable for retrieval. It will not be possible to process information if that particular information is not part of one's knowledge base, thus affecting performance on tasks of intellectual ability, memory, learning and educational achievement. Furthermore, reaction times provide evidence about the time course for information processing, eye movements yield information about attention over time, inferences can be made from what the subject remembers and/or forgets and the analysis of correct or incorrect responses can give clues as to the nature of development and reasoning (Flavell, 1985).
4.2: The study of attention: An information processing approach

Due to an interest in understanding how information is attended to, encoded, stored and retrieved, a number of models and theories, incorporating attention as an essential factor, have emerged. Some of these, which represent the growth and therefore, the expansion from basic to complex information processing models, are briefly outlined below. While psychological ("cognitive") models investigate behavioural processes in order to explain information processing, "neuropsychological" models attempt to link these behavioural processes to anatomical areas of the brain.

4.2.1: Psychological/cognitive models:

(i) Broadbent (1958)

The research on attention was highly stimulated by Broadbent (1958) who introduced the "human information processing" approach. Broadbent's model is described as a pipeline approach, or a filter model. In this approach, information (e.g.: color, loudness) reaches the sense organs and is coded in parallel. A filter is assumed to be located behind this stage of parallel processing. Stimulus identification and response selection take place in subsequent stages. Once passed the filter, operations occur by a stepwise and serial manner, with information finally stored into long-term memory (van Zomeren and Brouwer, 1994). This theory assumes that selection of information occurs immediately after abstracting raw physical features from the environment and that the filter excludes all irrelevant information. This view is now untenable since it has become obvious that individuals can be engaged in two events at the same time, for example, reading a book and responding if one's name is called (Anderson, 1991; Cooley & Morris, 1990; Van Zomeren, 1981). However, while untenable, provided important insights on which later models were built. Broadbent later adapted his model and introduced a mechanism called 'pigeonholing' which allowed for relative thresholds of responses on the output side of the system (Van Zomeren & Brouwer, 1994).
(ii) Shiffron and Schneider (1977)

These authors expanded on the pipeline model by proposing a "two process" model since it was evident, as stated above, that individuals were able to do two things at the one time. These authors distinguished between automatic versus controlled information processing. The former was described as occurring without conscious control (the result of practice and learning) where processing occurred in parallel, resulting in an unlimited capacity for processing. Controlled processing, in contrast, required the allocation of attention as was typically required in new situations where prior experience could not be utilised. In this theory, deficits of focused attention occur when automated responses interfere with a response produced by controlled processing, and a divided attention deficit results from the limited capacity of the system for controlled processing (Van Zomeren & Brouwer, 1994).

(iii) Cooley and Morris (1990)

Cooley and Morris (1990) presented a more complex model, comprising four different levels of processing. The most basic level is that of arousal and this regulates the general information processing capacity. At the second level are the sensory regulation units which are modality linked, followed by the third level which is considered modality specific (contains basic perceptual information that requires additional processing above sensory information). The fourth stage is more complex and involves the translation of information across cognitive systems (e.g.: learning, memory and linguistic processing). Another contribution of this model is that it emphasised the developmental trends present in all levels of processing and that it is the development of specific cognitive and neuropsychological functional systems that seem to have the greatest impact on a child's capacity to perform most attentional tasks, a related developmental factor being the emergence of the executive system.

(iv) Cohen and O'Donnell (1993)

Cohen and O'Donnell (1993) organised attentional mechanisms into four components, and unlike previous models, broke these mechanisms into individual,
yet inter-related components such as selective attention, attentional capacity, response selection and sustained attention: (i) sensory selective attention was categorised into selective/focused attention and automatic processes and considered to be motivated by top-down or bottom-up processes. Selective attention occurred when some stimuli were filtered and others were attended to for further processing; (ii) attentional capacity was seen as an important notion since humans cannot process infinite amount of information. Structural capacity included working memory and processing speed limits, where-as energetic properties included levels of arousal, effort and motivation; (iii) response selection was seen as an important component of attention as one first has to select the best alternative before working towards goal attainment and (iv) sustained attention required the maintenance of sensory selection, capacity and response selection over time, and so was thought to be vulnerable to a deficit in any of the other components.

(v) Cowan (1988) and Baddeley (1990)

These models are linked by the use of a central executive that directs the process of voluntary attention, and so is comparable to a "supervisory attentional control". The model by Cowan (1988) has features such as a brief sensory store, the focusing of attention, short and long term memory and controlled versus automatic actions (Anderson, 1991). Baddeley's (1990) is linked to a phonological loop and a visual-spatial sketch pad. The phonological loop is responsible for speech-based information and the visual sketch pad for setting up and dealing with visual images (Anderson, 1991; Baddeley, 1990; van Zomeren & Brouwer, 1994).

These cognitive models, in their attempt to understand and describe the role of attention in an information processing model, have ranged from pipeline to dual processing to interactive models. What these models have in common is that they all describe a series of features which information should pass through efficiently, in order to be processed accurately and quickly. However, they do not attempt to link components of processing (e.g.: attention) to anatomical areas of the brain, limiting their applicability to neuropsychological contexts.
4.2.2: Neuropsychological models:

Neuropsychological models attempt to understand what information processing is and how it takes place, and it identifies regions in the brain associated with individual components of information processing. A similarity in these models, as well as the psychological models, is the underlying components of information processing that are attempted to be described, localised and measured. Such components include sustained attention (vigilance), selective attention (focused), divided attention, and switching of attentional focus and speed of information processing (efficiency).

(i) Luria (1973)

From the large number of visual and auditory stimuli which reach us, we respond to those that are necessary for the completion of an immediate task. This directivity and selectivity of mental processes and the basis on which they are organised may be known as "attention" (Luria, 1973). Luria (1973) based his work on brain-injured patients and distinguished between innate and voluntary attention. While innate attention is biologically based, he stated that voluntary attention is in fact not at all biological, but is a social act. That is, the child's voluntary attention develops from an externally-socially organised attention which then becomes an internal self-regulating process.

Luria (1973) also described the cerebral structures which may be implicated in attention. He stated that the brainstem and the reticular formation are important in the maintenance of general arousal. The limbic region (hippocampus and the amygdala) is essential for the elimination of responses to irrelevant stimuli and so made it possible for selectivity to take place. The role of the frontal lobes was seen to be the inhibition of responses to irrelevant stimuli, the preservation of goal directed behaviour and a role in the maintenance of sustained attention.

(ii) Posner and Petersen (1990)

These authors have been influential in this field, combining experimental techniques and investigating developmental aspects of attention while studying
areas of deficit. Posner and Petersen (1990) postulate that attention is anatomically separate to data processing systems and is carried out by a network of anatomical areas, and that these areas carry out different functions. They divided attention into three subsystems that perform different but interrelated functions: (i) orienting to sensory events; (ii) detecting signals for focal (conscious) processing and (iii) maintaining a vigilant or alert state. Orienting to visual events related to attending to a stimulus in a particular location and so involved the shifting and disengaging of attentional focus. The parietal lobe was purported to disengage attention from its present focus, the midbrain moved the index of attention to the target and the pulvinar was involved in getting information from the indexed locations. Target detection, was seen as a role of the anterior cingulate gyrus as this area was found to respond when the number of targets to be detected increased (Posner, 1988 as cited in Posner & Petersen, 1990). Alerting and vigilance were considered important when processing high priority signals and seemed to be dependent upon the integrity of the posterior attention systems of the right hemisphere (Posner & Petersen, 1990).

(iii) Posner and Rothbart (1992)

Posner and Rothbart (1992) continued the investigation of anatomical brain regions involved in attentional processes, and differentiated between the posterior and anterior brain systems and their role in attention. The posterior network was described as involving a set of cortical, midbrain and thalamic areas, which included portions of the parietal cortex, associated thalamic areas of the pulvinar and reticular nucleus and part of the midbrain’s superior colliculus. This network was reported to be involved in orienting to sensory stimuli, directing attention to locations and visual search. The anterior system was considered to be mainly involved with volition and the emergence of language.


Stuss et al. (1995) discuss issues of attention in the context of frontal lobe functioning specifically. They describe four components for cognitive processing: (i) cognitive units or modules; (ii) schemata; (iii) contention scheduling and (iv)
supervisory (attentional) system (based on Shallice, 1982). While (i) to (iii) are related to routine activities, the supervisory attentional system was seen as the central executive, which handled non-routine behaviours, functioning via top-down activation or inhibition of schemata. Five independent supervisory processes relate to the frontal lobes: energising schemata, inhibiting schemata, adjusting contention scheduling, monitoring the level of activity in schemata and control of if-then logical processes. These authors postulate that the control of attention is shown in seven types of tasks, and so are able to link brain regions to tests: (i) sustaining attention (vigilance) - where the main processes are monitoring, energising and inhibiting, with the possible anatomical basis in the right frontal lobe; (ii) concentrating attention (when the task is demanding and the required responses are occurring too quickly) - where inhibiting, energising, adjustment of contention scheduling where the processes of importance and where the basis may be the anterior cingulate; (iii) sharing attention (when two or more unrelated tasks are to be carried out at the same time) - where energising and monitoring processes are involved and the cingulate orbitofrontal is the possible anatomical area; (iv) Suppressing attention (when automatic processes select schemata that are inappropriate to task requirements) - where logic and inhibiting are the component processes and may be found in the dorsolateral area; (v) switching attention (shifting of attention) - which involves inhibiting and energising processes and may be subsumed by the dorsolateral and medial frontal areas; (vi) preparing attention (when an operation is to be carried out later in time) - which is reliant upon energizing processes and is possibly found in the dorsolateral area and (vii) setting attention (relates to the consistent mobilisation of the most appropriate schemata across testing sessions) - where the main component processes are energizing and monitoring with the possible anatomical basis being the left dorsolateral area. In this theoretical viewpoint, the processes may exist at many levels of the brain, including more posterior (automatic) processes. The frontal lobes have extensive connections with all brain regions and so this allows the integration of information from other regions, and thus provide a sophisticated control of attention.

Mirsky et al. (1991, 1996) provide a clinically relevant model for conceptualising the components of attention. The model presents four elements of attention and links them to a system of cerebral structures, while suggesting ways of assessing the four components of attention, using tests that span across the age range, from paediatrics to adulthood. Data that provide support for the model are derived from an adult sample of neuropsychiatric patients, and a control sample of ‘normal’ elementary school children. Principal components analysis using the two data sets yielded a set of independent components of attention, that can be investigated using different tests.

Using statistical approaches, they derived three factors corresponding to the dimensions of sustaining, focusing and shifting:

1. **Sustained attention (vigilance):** the capacity to maintain focus and alertness over time and seems to be the responsibility of the midbrain structures (including the mesopontine reticular formation and midline and reticular thalamic nuclei) and the brainstem.

2. **Selective attention (focused attention):** the ability to select target information from an array for further processing while ignoring irrelevant stimuli (the differential processing of simultaneous sources of information), and appears to be subserved by the temporal and parietal areas of the brain as well as some subcortical structures, such as structures comprising the corpus striatum.

3. **Shift:** the ability to change attentive focus in a flexible and adaptive manner and appears to be the responsibility of the pre-frontal areas, perhaps also including the medial frontal cortex and the anterior cingulate gyrus. (Mirsky, Anthony, Duncan, Ahearn and Kellam, 1991; Johnston and Dark, 1986).

The framework by Mirsky et al. (1991) breaks attention into groups of inter-related processes, with each one linked to cerebral structures that are often damaged following TBI. Certain tests are often used to measure these processes, which range
from basic to executive attentional functioning. The Continuous Performance Test (CPT) is often used to measure vigilance, the Trail Making Test and the Stroop Colour Word Interference Test (Stroop, 1935) are often used as measures of focused attention and the Wisconsin Card Sorting Test is a popular test of the shift element. It follows that damage or dysfunction in one of the brain regions believed to subserve a particular facet of attention, can lead to specific deficits in a particular attentional function.

Speed of processing, or the rate at which activities may be completed, is also incorporated into Mirsky's system, and is considered to underpin the efficiency of the system. Mirsky et al. (1991) also discuss an "encode" element which requires sequential registration, recall and mental manipulation of information (dependent on the hippocampus and the amygdala). Furthermore, Mirsky (1996) also make suggestion of a fifth element, that is, stability, which is related to the reliability of attentional effort.

4.2.3: Conclusions:

As is evident, there is no clear consensus with respect to information processing and the underlying bases, however there appears to be a number of components of information processing which are linked to each other. Further, it may be suggested that if one's attentional abilities in the areas of sustained, selective (focused) or shifting attention and speed of information processing are deficient, then it follows that the overall processing of information will be hampered. It will also become difficult to know, for example, whether a detected problem in short or long term memory is actually a manifestation of an attentional problem. Attention may be placed at the beginning of a continuum of information processing, which if deficient, will influence the remainder of this continuum.

4.3: Development of attention

As outlined previously in this chapter, there are many theories and models of information processing and specifically attention, however few focus on the developmental aspects of attention. It is essential to be aware of the developmental
aspects of the different components of attention in the ‘normal’ population in order to be able to delineate any impairments in clinical samples.

4.3.1: Sustained attention:

Some researchers have attempted to define attention and adopt a developmental approach when investigating individual components. Sustained attention or vigilance is that behaviour required to detect infrequently occurring signals over a prolonged period of time, when those signals are embedded in a background of regularly occurring events. The Continuous Performance Test (CPT), is often used as a measure of sustained attention (Anderson et al., 1973; Kelly, Best, & Kirk 1989; Lovejoy & Rasmussen, 1990; Melnyk & Das 1992; Noland & Schuld 1971; Richards, Samuels, Turnure, & Ysseldyke, 1990; Schonfeld, Shaffer, & Barmack, 1989), because: (1) children learn how to do it quickly; (2) experimental conditions are rigidly controlled; (3) there is uniformity in presentation; (4) response characteristics are measured accurately; (5) objective measures of attention are obtained (Anderson, Halcomb, & Doyle 1973). McKay, Halperin, Schwartz, and Sharma (1994) reported that sustained attention shows little development between seven and eleven years of age, but significant progress from age eleven into early adulthood.

4.3.2: Selective (focused) attention:

Research on the development of selective attention in children has investigated the increased selectivity that children show as they grow older. Younger children are less able to deploy attention efficiently in either focused or divided attention paradigms. Children perform less well on complex search, detection and classification tasks, probably due to a lower capacity of efficient information processing. By the age of 10-13 years these strategies appear to approximate the adult level of efficiency (Kaye, Toys, & Ruskin, 1990). Results from McKay et al (1994) showed that selective attention appears to mature to adult levels before the age of seven years, remaining relatively stable throughout middle and late childhood.
Lane and Pearson (1982) further elaborated the above information relating to age differences in selective attention and concluded that in some paradigms, the presence of irrelevant information will affect the performance of younger children more than that of older children and adults. Of importance, it was found that young children do not waste their resources by processing irrelevant messages more so than the older group, but that they have more difficulty separating messages and then reporting the correct one. This further stresses the need to investigate the manner in which irrelevant stimuli cause interference. A number of studies (Copeland & Reiner, 1984; Pelham, 1979), have assessed selective attention in an attempt to distinguish between learning disabled and non learning disabled children.

4.3.3: Shifting attention:

The ability to accommodate change in cognitive set (shifting attention) was found to develop rapidly between seven and nine years of age, at which point these skills were at adult levels (McKay et al., 1994). More generally, Rebok et al., (1997) found that most rapid gains in attentional performance (encoding, selective attention, shifting attention and sustained attention) were seen in children from ages 8 to 10 years, with more gradual changes between the ages of 10-13 years.

4.3.4: Speed of information processing:

The developmental trajectories of these skills appear better defined in the literature. Johnson, Roethig-Johnston, and Middleton (1988) reported that processing speed also increases exponentially with age, where children under 9.5 years performed significantly differently to older children, revealing that children below 9.5 years of age have a slower rate of information processing. Other studies have also reported age differences in speed of processing (Kail, 1986), where 10 year olds were reported to be 1.8 times slower than young adults, and 12 year olds were approximately 1.5 times slower, where-as 15 year olds were similar to young adults (Hale, 1990). These results high-light the importance for longitudinal investigation during childhood and adolescence (Dennis, Wilkinson, Koski, & Humphreys, 1995).
4.4: Conclusions

The brain areas commonly damaged following a closed head injury (e.g.: frontal regions, white matter), are those areas purported to subsume the attentional system. Therefore, it is not surprising to expect, that following such an injury, that children will have difficulty in these areas. Furthermore, taking into account the developmental aspects, it may be argued that children who have sustained an injury often do so before these skills are fully developed, therefore the injury may impact on the current capacity of that skill, as well as hindering its normal progress in the future. A deficiency in these attentional and speed of processing skills may then impact on subsequent learning and adaptive skills. It may be suggested that the effects of such an injury may be better understood within the context of an information processing model (Gentilini, Nichelli, & Schoenhuber, 1989 cited in Beers, 1992) which regards attentional capacity as the possible underlying influence affecting other areas of functioning.
Chapter 5:

Attentional skills following TBI

5.1 Introduction - Attention

Research in the area of attentional ability following TBI remains quite scarce (Timmermans & Christensen, 1991), with additional need for further investigations of normal developmental processes in this area. While attentional impairments have been identified clinically post paediatric TBI, there are few studies in the area despite its importance to development. The present chapter summarises both adult and paediatric studies, some of which incorporate, as a theoretical basis, Mirsky’s model of attention (Mirsky’s et al., 1991). Attentional components such as sustained attention, selective attention, shifting attention and speed of processing, the latter affecting the efficiency of the whole system are investigated.

5.1.1: Adult literature:

Stuss et al. (1989) compared three groups of patients who had suffered a closed head injury and contrasted their performance to controls on reaction time tasks. The first group of patients were subjects who were previously hospitalised for a head injury with varying degrees of severity. The second group was comprised of non hospitalised mildly concussed patients and the third group included a group of closed head injured patients, with varying degrees of severity, who were assessed 7-10 months after initial hospitalisation. Results showed that TBI causes slowness in information processing, deficits in focused and divided attention and inconsistency of performance. Van Zommeren and Fasotti (1992) reported that focused attention is usually unimpaired following brain damage, with deficits only obvious when frontal lesions were apparent. Yet, divided attention was found to be very often impaired as a result of poor information processing, especially when time restrictions were imposed. Conversely, also cited are specific speed of processing and motor response deficits, with otherwise intact attentional abilities (Ponsford & Kinsella, 1992).
Shum, McFarland, Bain and Humphreys (1990) employed a more ‘experimental’ model of attention. Attentional processes were examined in terms of four information processing stages and these included feature extraction, identification, response selection and motor adjustment. Task variables were also utilised to operationalise the four stages and these were known as signal quality, signal similarity, signal response compatibility and foreperiod uncertainty. Subjects consisted of three groups of closed head injured subjects (adolescents to adults in age), with group one exhibiting a GCS of less than 8, group 2 a GCS of 8 or less on admission and group three a GCS of 14-15 on admission. The first group was tested less than one year after injury, the second group was tested at least one year after injury and the third group was assessed approximately one month after injury. The results indicated that patients and controls exhibited linear information processing. However, group one was impaired on the identification, response selection and response execution stages, group two was impaired on the response selection and response execution stages and the third group showed no deficits.

In a follow-up study, Murray, Shum, & McFarland, (1992), divided TBI subjects into a severe and a mild/moderate group. They found that the severe group was deficient in motor execution and response selection stages, with no impairments found for the mild group. The importance of these studies is the fact that they present an information processing model and from this model then it can be seen with more clarity where children, adolescents or adults have deficits.

5.1.2 Paediatric literature:

A small number of studies have recently emerged investigating attentional skills, following childhood TBI. Ewing-Cobbs et al. (1998) demonstrated impairments in the areas of selective, sustained and shifting attention. Timmermans and Christensen (1991) investigated 38 subjects (aged between 5 and 16 years), and also reported difficulty in the maintenance of attention over time, using a Continuous Performance Task (CPT). Similarly, Kaufmann, Fletcher, Levin, Miner, and Ewing-Cobbs (1993) reported that children with a severe closed head injury,
and more specifically the younger children in the sample, demonstrated significantly poorer sustained attention than mild or moderate head injured children.

Furthermore, Anderson & Pentland (1998) and Ewing-Cobbs et al. (1998), also reported difficulties on tasks with a speeded component, indicating that attentional tasks tap a number of skill areas (Stuss, Stetham, & Poirer, 1989), one often being speed of processing. Within test ‘scatter’ or variability of performance following TBI was also reported when qualitative differences were evident on a digit span task, a more traditional measure of attention, comparing children aged between 7-15 years with a comparison group (Warschausky, Kewman, & Selim 1996).

Residual deficits were also documented in a recent paper (Anderson, Fenwick, Manly, & Robertson, 1998), employing a componential model of attention, identifying sustained, focused and divided attention as separable processes, consistent with van Zomeren and Brouwer’s (1994) approach. Results indicated that attentional skills may be differentially impaired following a moderate to severe injury. While focused attention was found relatively intact, deficits were found in the areas of sustained attention, divided attention and response inhibition.

5.1.3: Conclusions:

In summary, it is evident that the literature on attention and information processing in the area of paediatric head injury is extremely limited. The few studies that are available differ in their methodologies and theoretical backgrounds. It is often stated that following brain trauma, the information processing system of the brain will be impaired, imposing limitations on functions such as memory and learning. If attention is deficient, then the amount of processing that takes place will also be poor and will in turn affect the functioning of other areas, such as memory and learning. Therefore, it may be suggested that attention may be the underlying factor affecting outcome in a number of areas following a head injury. The importance of research in the area of attention and paediatric TBI is obvious, especially since this may be a major factor underlying many areas of difficulty which become problematic in the classroom situation. As summed by Adamovich
(1990), basic arousal, vigilance and selective attention are essential if one is to integrate and interpret information.

What has become quite clear is that there is only limited research on the recovery, over time, of attentional skills following paediatric TBI. However, from these limited studies it is obvious that sequelae in childhood are different from those following a head injury in adulthood. Adult literature suggests that following a closed head injury deficits are not commonly seen in areas such as sustained attention, selective attention or response inhibition, but most likely in the reduced speed of information processing (Brouwer, Ponds, Wolffenbarger, & van Zomeren, 1989; Ponsford & Kinsella, 1992; Spikman, van Zomeren, & Deelman, 1996; Zwaagstra, Schmidt, & Vanier, 1996). However, due to different developmental trajectories for components of attention during childhood (McKay, Halperin, Schwartz, and Sharma (1994), and the cross-sectional nature of most studies, there is less evidence on the type of attentional impairments, and of the recovery profiles of attention, following paediatric TBI. As children present with variable attentional problems depending on the age of the child (Dennis et al., 1995), the severity of injury (Byrne, 1998), and the model or theory of attention used to measure these skill areas, it is essential that any investigation of attention in childhood specifies the theory or model underlying that particular research study (Fletcher, 1998).

5.2: Speed of processing outcomes:

Another facet of functioning which may be affected following TBI is speed of information processing. One of the key characteristics of patients who have sustained a traumatic head injury is their mental slowness (Ponsford & Kinsella, 1992; Stuss et al., 1989), as reflected by longer reaction times and deterioration of performance on tasks which are time limited.

5.2.1 Adult literature:

Tromp and Moulder (1991) investigated a group of adult patients and it was queried why processes are carried out slower but otherwise correctly. Anderson (1976, 1882, 1987) cited in Tromp and Moulder (1991) further elaborated the issue
of mental slowness by describing an associate network of interconnected nodes containing information. Activation states spread across the network along the connections between the nodes. If routes are activated repeatedly then memory traces become established. The speed of information processing is determined by the strength of the connections between nodes and also by the way the information is organised.

Continuing on possible causes of mental slowness, Dowell (1981) and Anderson (1987) both cited in Tromp and Moulder (1991) described the way information is organised. Knowledge is stored redundantly, that is that there are multiple access routes to reach the stored information. Further-more, knowledge is divided into declarative knowledge (specifies facts about the world) and procedural knowledge (specifies how something is done). If connections are redundant, they should not be very vulnerable to brain damage. Thus it was suggested that following diffuse shearing of fibres, as seen in closed head injury, tasks that require more complex information processing are affected. It follows that the effects on patients should be most evident on relatively novel tasks rather than familiar tasks. The explanation given is that declarative information, that is, the "what" of a new task will not be presented in a very redundant way and so it will be accessed more slowly. It was also predicted that increasing motor complexity will not effect performance because it is linked to procedural knowledge and is usually represented in a redundant way. Brouwer (1985) further suggested that the main cause of the general slowness is a delayed access to stored knowledge. Since every act is the result of a continuous interplay between stored knowledge and cognitive processes, if it is difficult to retrieve the stored knowledge then slowness will result.

Tromp and Moulder (1991) recruited ten subjects with a mean age of 24 years and a mean duration of coma of 14 days and compared them to ten subjects who were matched with respect to age, sex and educational level. Subjects were asked to copy 48 stimulus figures of varying complexity and familiarity, as quickly and as accurately as possible. Task execution was recorded on a graphic digitiser. As was hypothesised, it was found that novelty but not motor complexity had a crucial
influence on the speed of information processing following a head injury, implying that the deficit involves the general problem of memory activation rather than a specific stage of information processing such as motor skills.

The above findings were linked to the neuroanatomical organisation of the brain as described by Goldberg and Costa (1981) cited in Tromp and Moulder (1991). That is, when reviewing the differential role of both brain hemispheres is was concluded that the left hemisphere is superior in the use of well established routines and familiar codes whereas the right hemisphere is superior in working with novel information. The left hemisphere is said to have more cells than fibres, yet, the right hemisphere has more fibres and interconnected association areas than cells. Thus it follows, that in the shearing of axon tissue, the right hemisphere will be more affected than the left and so the processing of novel information will be most influenced.

Other research papers have not examined the issue of mental slowness in such depth, but have instead investigated performance on tasks which measure reaction time. Miller (1970) compared the performance of five head injury subjects (aged 18-28 years with PTA lasting more than one week) to five control subjects using the Continuous Performance Test of Rosvold, Mirsky, Sarason, Bransome, and Beck (1956). Despite the small sample, it was found that the head injured group had slower reaction times in comparison to controls and that the discrepancy increased with task complexity. As in the study by Tromp and Moulder (1991), it was concluded that a central, rather than a sensory or motor disturbance reduced the speed of information processing.

MacFlynn, Montgomery, Fenton, and Rutherford (1984) also investigated a group of "older" subjects aged between 16-55 years at time intervals of 24 hours and 6 weeks after the injury. The subjects were comprised of 45 minor head injury cases (28 of these were also retested at 6 months post-injury). A control group of general practice patients were matched on variables such as sex, age, marital status, social and intellectual status. Subjects were assessed using a four-choice reaction
time recorder (Wilkinson & Houghton, 1975 cited in Macflyn et al., 1984). It was reported that the TBI cases displayed significantly poorer performance than the controls up to 6 weeks post-injury. However, the patients improved in these measures up to 6 months post-injury, when their scores exceeded those of the control group. This study suggests that any deficits in reaction time are only transient in this group of mildly injured (PTA less than 24 hours) patients. Similarly, van Zomeren (1981) found that simple and, especially choice reaction time tasks, discriminated between patient and control groups. It was found that the ‘slowing down’ after a head injury is at least partially a result of a slowing in central processes such as decision making and response selection, rather than a deficiency in motor performance.

5.2.2 Paediatric literature:

The literature presented has been investigating reaction time deficits in adult subjects, since there is a paucity in studies relating to children. However, the information obtained from this older age group may not be applicable to children, especially when taking into account the developmental changes in the speed of cognitive processing from childhood to adulthood (Hale, 1990; Kail, 1986).

Bawden, Knights, and Winogron (1985) conducted a study with fifty-one children who had sustained a head injury. The children were divided into a mild group (loss of consciousness less than 20 minutes and those with a linear fracture), a moderate group (unconsciousness longer than 20 minutes, neurological signs such as brain contusion or haemorrhage, (GCS between 8-14) and a severe group (GCS of 7 or less, in coma at time of admission, duration of coma ranging from 11-77 days). The three groups were matched for age, sex and the injury-test interval, with the mean age for each of the groups being 9.4, 9.5 and 9.6 years respectively. One year post injury, the subjects were tested on measures of speeded and non-speeded performance, visual motor and visual spatial functioning, as well as on the WISC-R. It was found that the mild and moderate groups performed similarly, both groups performing significantly faster than the severely injured group on the speeded tests. However, there were few significant differences on those tasks requiring little
speed. The main conclusion from this study was the finding that the severely head injured group was the most compromised and performed significantly worse than the other two groups on the highly speeded tests.

Chaplin, Deitz, and Jaffe (1993) added a further finding with regard to performance on timed tasks. These authors found that in a group of traumatically brain injured children, when speed was a component of either gross or fine motor tasks, then patterns of significant differences were found between this group of children and controls. These results suggest that poor performance on timed tasks may in some cases be due to poor gross and/or fine motor skills, rather than to a purely cognitive processing capacity.

5.2.3: Conclusions:

In light of the studies presented, it may be suggested that the most severely injured children are those that suffer most diffuse damage to nerve fibres. The findings in this section seem to suggest that mental slowness does occur, at least in the moderate to severe groups. However, much of the literature is based on adult subjects and only preliminary explanations have been put forth to account for the deficits reported. More research focusing on slowed information processing and the processes underlying it (e.g.: attentional difficulties, motoric unsteadiness, deficits in decision making, developmental factors), which may be affected following a head injury in childhood, is needed.
Chapter 6:

The Present Study:

6.1: Introduction:

From the previous chapter, it is clear that the literature on attention and information processing in the area of paediatric TBI is limited. The few studies that are available differ in their methodologies and theoretical perspectives. Most are cross-sectional and unable to address the issues of recovery and the possible effects of attentional impairments on development post-injury. In fact, neuropsychological studies of paediatric TBI have not adequately reported functional outcomes in terms of specific scholastic and social deficiencies (Berger-Gross & Shackelford, 1985), and these may be particularly linked to attentional function. As stated by Milton, Scaglione, Flanagan, Con and Rudnick (1991), the classroom and the demands of academic activities require that each student is able to deal with cognitive, communicative, visual-spatial, physical and psychosocial challenges and the integration of these skills, often dependent on the efficient use of attentional capacity.

Since attention may be an essential first step in a model of information processing (see Figure 6.1), subsequent processes are reliant on its efficiency. If attention is deficient in one or more component, that is sustained attention, selective attention, shifting attention and speed of processing, then this may impinge on memory and learning, which in turn may affect the efficient acquisition of educational and adaptive skills. Therefore, it is essential to ascertain the degree of attentional deficits following head trauma so that the link between attention and other skills is better understood and so that remedial and rehabilitation services can be more meaningful and focused in their approach.

6.2 Aims:

Taking into account the paucity of research in the attentional area following paediatric TBI, and the importance of attentional skills as part of an information processing model, the present study has the following aims:
The broad aim of the present study is to investigate information processing skills (attention, speed of information processing, memory and new learning), in children following mild, moderate or severe TBI, as these are necessary for the successful development of academic and adaptive functioning. To do this, the study will employ a componential neuropsychological model of attention to determine whether identified deficits are of a generalised nature (e.g.: difficulties with attention, speed, memory and new learning), or are specific to particular aspects of information processing (e.g.: primarily attentional difficulties are evident). Further, the study aims to (i) document the recovery profiles of intellectual, educational and information processing skills over a two year period post-injury; (ii) investigate the possible relationship between attentional deficits and the development of educational and adaptive skills post-TBI and; (iii) identify children who are at risk
for future educational/social problems, allowing interventions to be implemented before long-term educational/social difficulties emerge.

6.3 Method:

6.3.1 Participants

The sample comprised 76 children who had sustained a documented closed head injury, and represented consecutive admissions to the neurosurgery ward of the Royal Children's Hospital, Melbourne, between June 1994 and December 1997. Of these children 55 were male and 21 were female. Inclusion criteria were: (i) aged between 8-12 years at time of injury; (ii) documented evidence of closed head injury, including period of altered conscious state; (iii) medical records sufficiently detailed to determine severity of injury, that is, including Glasgow Coma Scale (GCS: Teasdale & Jennett, 1974), post-traumatic amnesia (PTA: length of time from accident until orientation to person, time and place), neurological and radiological findings. Exclusion criteria were: history of neurological or developmental disorder, previous head injury, documented learning or attentional disability.

TBI children were categorised into severity groups on the following basis: (i) mild TBI (n=27): GCS on admission of 13-15, loss of consciousness (LOC) less than one hour, PTA of less than 24 hours, and no abnormalities on CT or MRI scans; (ii) moderate TBI (n=33): GCS on admission of 9-12, LOC from 1-24 hours, and PTA from 1-7 days; abnormalities on CT or MRI (iii) severe TBI (n=16): GCS on admission of less than or equal to 8, LOC greater than 24 hours, PTA of greater than 7 days; abnormalities on CT or MRI. Implementation of these variables successfully categorised all 76 children. Tables 6.1 and 6.2 provide demographic and injury data for the sample.

As illustrated in Table 6.1, the groups did not differ with respect to gender, age at injury, time interval from injury to first assessment, socio-economic status (SES), or family constellation. Analysis indicated no group differences on the VABS (F(2,71)=0.69, ns), suggesting that any difference between the groups
post-injury could not be explained by pre-injury status. Mean performance for mild, moderate and severe TBI groups was within the "Average" range prior to injury.

Table 6.1: Demographic information for the sample

<table>
<thead>
<tr>
<th></th>
<th>Mild TBI</th>
<th>Moderate TBI</th>
<th>Severe TBI</th>
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<tbody>
<tr>
<td>n</td>
<td>27</td>
<td>33</td>
<td>16</td>
</tr>
<tr>
<td>No. males</td>
<td>19</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>Injury age (yrs) M (SD)</td>
<td>10.4 (1.3)</td>
<td>10.1 (1.4)</td>
<td>11.1 (1.5)</td>
</tr>
<tr>
<td>Injury-initial testing (mths) M(SD)</td>
<td>1.7 (1.1)</td>
<td>2.2 (2.4)</td>
<td>1.9 (1.2)</td>
</tr>
<tr>
<td>Socio-economic status* M (SD)</td>
<td>4.1 (0.9)</td>
<td>4.5 (0.9)</td>
<td>4.7 (1.1)</td>
</tr>
<tr>
<td>Intact families (n)</td>
<td>23</td>
<td>26</td>
<td>12</td>
</tr>
<tr>
<td>Vineland (VABS)-Pre-injury:</td>
<td>107.4 (15.2)</td>
<td>103.9 (15.6)</td>
<td>102.4 (11.8)</td>
</tr>
<tr>
<td>Composite score M (SD)</td>
<td></td>
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</tr>
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</table>

no significant group differences on these measures

* Daniel (1993)

As expected, there were group differences on all medical variables (see Table 6.2), with the severe TBI group presenting with significantly more complications than the other severity groups, apart from the number of fractures. Severe TBI was mainly due to motor vehicle accidents while moderate and mild injuries were mainly due to falls and blows to the head. Of the children presenting with neurological signs in the moderate and severe groups, two children exhibited a mild hemiparesis on the left side, three children had right sided weakness, one child was restricted to a wheelchair and had poor motor control, two children experienced seizures post injury and four children presented with hearing loss.
Table 6.2: Injury and medical characteristics of sample

<table>
<thead>
<tr>
<th></th>
<th>Mild TBI (n=27)</th>
<th>Moderate TBI (n=33)</th>
<th>Severe TBI (n=16)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cause of injury:</strong></td>
<td></td>
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<tr>
<td>MCA passenger (n)</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>MCA: pedestrian (n)</td>
<td>4</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Fall from roof/tree/bunk (n)</td>
<td>11</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Fall from bike/backwards</td>
<td>8</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Blow (n)</td>
<td>3</td>
<td>10</td>
<td>-</td>
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<tr>
<td><strong>Medical Characteristics:</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>GCS: admission M (SD)**</td>
<td>14.3 (1.1)</td>
<td>11.9 (3.0)</td>
<td>6.2 (2.5)</td>
</tr>
<tr>
<td>GCS: 24 hours M (SD)**</td>
<td>14.9 (0.2)</td>
<td>13.2 (2.1)</td>
<td>8.4 (2.9)</td>
</tr>
<tr>
<td>Coma &gt; 1 hour (n)</td>
<td>-</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>PTA &gt; 1 day (n)</td>
<td>-</td>
<td>16</td>
<td>16</td>
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<tr>
<td>Abnormal CT/MRI</td>
<td>-</td>
<td>29</td>
<td>16</td>
</tr>
<tr>
<td>Skull fracture (n)</td>
<td>6 (linear fract.)</td>
<td>18</td>
<td>11</td>
</tr>
<tr>
<td>Neurological signs (n)</td>
<td>-</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Surgical intervention (n)</td>
<td>-</td>
<td>16</td>
<td>13</td>
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</tbody>
</table>

** p< 0.01

6.3.2 Measures

Below is an outline of the measures and an indication of the time points when they were administered (see Table 6.3). A brief description also follows, with more detail provided for each measure in subsequent chapters (see Appendix 1 for a copy of the questionnaires and the test materials administered).
Table 6.3: Summary of test protocol:

<table>
<thead>
<tr>
<th>Measures:</th>
<th>Pre-injury</th>
<th>0-3 months</th>
<th>6 months</th>
<th>12 months</th>
<th>24 months</th>
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<tr>
<td>Medical information:</td>
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<tr>
<td>MQ</td>
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<tr>
<td>Parental questionnaires:</td>
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<tr>
<td>EQ</td>
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<tr>
<td>RBRI</td>
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<tr>
<td>VABS</td>
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<td>Teacher questionnaires:</td>
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<tr>
<td>RBRS</td>
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<tr>
<td>Rowe-E</td>
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<tr>
<td>Child assessment:</td>
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<tr>
<td>Intellectual measure</td>
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<tr>
<td>WISC-111</td>
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<tr>
<td>Information processing</td>
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<tr>
<td>(i) Attention:</td>
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<tr>
<td>(a) Sustained attention</td>
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<tr>
<td>CPT</td>
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<tr>
<td>(b) Selective attention</td>
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<tr>
<td>LCT</td>
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<tr>
<td>TRAILS A</td>
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<tr>
<td>(c) Shifting attention</td>
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<td>TRAILS B</td>
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<tr>
<td>CNT</td>
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<tr>
<td>(ii) Memory and learning</td>
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<td>DF</td>
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<td>LSS</td>
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<td>BS</td>
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<td>CFRR</td>
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<tr>
<td>WRAML- verbal</td>
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<tr>
<td>WRAML- visual</td>
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<tr>
<td>Educational ability</td>
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<tr>
<td>WRAT</td>
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<tr>
<td>WIAT</td>
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</table>
Description of materials used:

Medical information:

Medical Questionnaire (MQ): recorded relevant medical data, including GCS scores, period of unconsciousness, duration of post-traumatic amnesia, neurosurgical interventions, neurological signs, and radiological results.

Questionnaires to be filled by parents:

(a) Epidemiological Questionnaire (EQ): documented parental occupations, socio-economic status, educational level, family constellation, medical and developmental history of the child.

(b) Rowe Behavioural Rating Inventory (RBRI: Rowe and Rowe, 1989): investigated the child's pre and post-injury attentional capacity.

(c) Vineland Adaptive Behavior Scale (VABS: Sparrow, Balla, & Cicchetti, 1984): described the child’s pre and post-injury adaptive level of functioning.

Questionnaires to be filled by the teacher:

(a) Rowe Behavioural Rating Inventory (RBRI: Rowe and Rowe, 1989): investigated the child's pre and post-injury attentional capacity.

(b) Rowe-Educational (Rowe-E): described the child's pre and post-injury performance in English, Reading, Spelling, and Mathematics.

Child assessment:

Intellectual measure:

Information processing skills:

(i) Attention:

(i) Sustained attention:

The Continuous Performance Task (CPT: modified version of Rosvold et al., 1956): A test used to examine the ability to maintain performance over time as well as speed of information processing.

(ii) Selective Attention:- Focused:

Two tests were administered, each tapping visual selective attention and processing speed:

(a) Letter Cancellation Test (LCT: Talland, 1965).

(b) Trail-Making Test - Part A (TRAILS: Reitan & Davison, 1974)

(iii) Shift

Two measures were employed to tap mental flexibility:

(a) Trail-Making Test - Part B (TRAILS: Reitan & Davison, 1974).


Memory and learning:

(a) Digits Forward (DF: Wechsler, 1974): A test of immediate memory for auditory-verbal material

(b) Luria Short Stories (LSS: Anderson et al, 1995a; adapted from Christenson, 1979): A measure of short-term verbal memory

(c) Block Span (BS: Milner, 1971): A test of short-term visual memory

(d) Complex Figure of Rey, recall (CFRR: Rey, 1941): A measure of short-term visual memory.
(e) **Wide Range Assessment of Memory and Learning** (WRAML: Adams and Sheslow, 1990): A multi-trial verbal learning task, with a delayed trial.

(f) **Wide Range Assessment of Memory and Learning** (WRAML: Adams and Sheslow, 1990): A multi-trial visual learning task, with a delayed trial.

(iii) **Educational Ability:**

(a) **The Wide Range Achievement Test - 3** (WRAT-3: Jastak and Wilkinson, 1984). A measure of Reading, Spelling and Arithmetic skills.

(b) **Wechsler Individual Achievement Test** (WIAT: Wechsler, 1992). A measure of Listening Comprehension.

6.3.3: **General procedure:**

Parents of children who met the selection criteria were invited to participate in the study. The research study was introduced and explained in detail and written consent was obtained, according to hospital ethics guidelines. Once the family had given consent for participation the appointment times were scheduled and the epidemiological questionnaire and the Vineland Adaptive Behavior Scale (Sparrow et al., 1984) were completed, based on pre-injury status. Acute assessment was conducted once acute neurological dysfunction, post-traumatic amnesia, had resolved. During the acute stage (0-3 months post injury) the total test battery was administered in three one hour sessions.

The attentional measures were then repeated at six months post-injury in a one hour session at the hospital and during this time parents completed the required questionnaires. Similarly, at twelve months children were again seen at the hospital for two one hour sessions in order to complete the assessment battery. Again parents filled out the required questionnaires and were seen for a short time after the assessment, in order to complete the neurobehavioural questionnaire. The same procedure was followed at twenty four months post-
injury. The children were seen for three one hour sessions and parents filled out the relevant questionnaires while waiting. At each of these stages, the relevant teacher questionnaires were sent to the child’s classroom teacher.

All assessments were conducted by a qualified psychologist and took place at the Royal Children’s Hospital. Order of test administration was fixed, with WISC-III completed in one session and other measures in the second and third session.
Chapter 7

Recovery of intellectual ability following paediatric traumatic brain injury

7.1: Introduction:

Cognitive status is an important consideration when examining skills such as attention, memory, learning and educational ability. It is essential to be able to differentiate between a child who presents with a profile where all skills are generally depressed, from a child who presents with age appropriate intellectual capacity, but struggles in particular areas such as attention and memory, in order that relevant interventions can be implemented. The importance of cognitive skills following a traumatic brain injury (TBI) has resulted in a number of research papers investigating intellectual ability following mild, moderate and severe TBI (Anderson et al., in press; Brown et al., 1981; Dikeman et al., 1990; Fay et al., 1993).

Fay and colleagues (1993), conducted a study with fifty-three subjects between the ages of 6-15 years, who had sustained a mild TBI. The head injured children were assessed three weeks and one year post-injury on tests including the Wechsler Intelligence Scale for Children - revised (WISC-R), and the Wide Range Achievement Test (WRAT). Few identifiable significant differences were evident between the TBI group and a control group. It was concluded that mild TBI has no significant long-term effects. Alternatively, others have reported significant differences between children who sustained a mild TBI and matched controls (Guldrandson, 1983; Tremont, Mittenberg, & Miller, 1999; Wrightson et al., 1995), indicating that even in a mild TBI, due to the stretching and shearing of neuronal fibres, a variety of neurochemical events, and diffuse damage, the brain is susceptible to injury (Bassett & Slater, 1990; Yeates, 2000).

Unlike the uncertainty about the absence or presence of long-term effects following mild TBI, the literature investigating intellectual functioning following severe TBI reports long-term sequelae for this group (Brink et al., 1970; Dikeman et al., 1990; Ong, Chandran, Zasmani, & Lye, 19998). Chadwick et al. (1981)
assessed children four months, one year and then two and one quarter years post-injury. These authors reported a persistent deficit on the WISC Performance IQ measure and a transient deficit on the WISC Verbal IQ measure.

Other researchers have compared children across the severity spectrum (mild, moderate and severe). While much research has been conducted at one time point (Chadwick et al., 1981; Winogron, Knights, & Bawden, 1984), fewer studies have employed a longitudinal design (Ewing-Cobbs et al., 1997; Jaffe et al., 1992, 1993, 1995). These researchers all reached similar conclusions where a dose-response relationship was evident between injury severity and cognitive outcome. The severe group performed more poorly than the mild-moderate TBI groups on measures of intellectual ability, as well as on other neuropsychological tests, providing strong validation for persisting deficits in children with more severe injuries.

Of the longitudinal studies employed (Ewing-Cobbs et al., 1997; Jaffe et al., 1992, 1993, 1995), most report recovery of Verbal IQ and Performance IQ immediately post-injury, with greatest improvement in the first six to twelve months post-injury, this being followed by a plateauing effect. Performance IQ is reported to show the largest discrepancy between severity groups, compared to Verbal IQ, which appear to be much less affected post-injury. It may be argued that Performance IQ is a measure of fluid skills, such as problem-solving and speed of response, and so may be more susceptible to the effects of a brain injury, whereas Verbal IQ is a measure of more established/crystalised skills, such as general knowledge, and so is less vulnerable following TBI (Fay et al., 1994; Jaffe et al., 1992, 1993, 1995; Knights et al., 1991; Winogran & Knights, 1984).

The present study aimed to extend the findings of previous research, employing a standardised test of intellectual ability that provides both psychometric reliability and clinical relevance, using a prospective longitudinal design. Based on previous findings, it was hypothesised that: (i) there will be a dose-response relationship between injury severity and performance on intellectual measures; (ii) all TBI
groups will show skill development over the two years post-injury, with the severe TBI group presenting a slower rate of development, therefore continually performing more poorly than the mild and moderate TBI groups; (iii) children who sustained severe TBI will show recovery for fluid skills (PIQ), with VIQ, which is reported to be less vulnerable following TBI, remaining relatively stable over the two years.

7.2: Method:
7.2.1: Participants
The sample comprised 70 children (6 children were deleted from the total sample due to missing data) who had sustained a documented TBI, and represented consecutive admissions to the neurosurgery ward of the Royal Children's Hospital, Melbourne, between June 1994 and August, 1997. Of these children, 52 were male and 18 were female. For inclusion and exclusion criteria, and for categorisation of severity groups refer to Chapter 6.

7.2.2: Measures:

Pre-injury questionnaires
(a) Epidemiological Questionnaire documented parental occupations and educational level, family constellation, and medical and developmental history of the child. Socio-economic status was recorded according to Daniel's Scale of Occupational Prestige (Daniel, 1983), where a low score reflects high occupational prestige. The scale ranges from 1.0 to 6.9.

(b) Medical Questionnaire: This questionnaire was based on data recorded in the child's medical record, including GCS scores, period of unconsciousness, duration of post-traumatic amnesia, neurosurgical interventions, neurological signs, and radiological results.

(c) Vineland Adaptive Behavior Scale (VABS: Sparrow, Balla, & Cicchetti, 1984):
this questionnaire was completed by parents, at the time of recruitment to the study, while the child was still in hospital. Parents were asked to describe their child's pre-injury abilities. The VABS provides a global measure of adaptive functioning, as well as scores for the domains of Communication, Daily Living, and Social Skills. Each domain is standardized, with a mean of 100 and a standard deviation of 15.

**Child Assessment**

**Intellectual Measure**: The Wechsler Intelligence Scale For Children - Third Edition (WISC-111: Wechsler, 1991) assessed general intelligence. Scores employed in analyses:-(i) IQ scores: Verbal (VIQ), Performance (PIQ), and Full Scale Intellectual Quotient (FSIQ); (ii) Index scores: Verbal Comprehension (VC), Perceptual Organisation (PO), Freedom from Distractability (FFD), and Processing Speed (PS). All scores have a mean of 100 and a standard deviation of 15; (iii) Individual subtest scores: Verbal subtests - Information (INF), Similarities (SIM), Arithmetic (ARI), Vocabulary (VOC), Comprehension (COM); Performance subtests - Picture Completion (PC), Coding (CD), Picture Arrangement (PA), Block Design (BD), Object Assembly (OA). (iv) Optional subtest scores - Symbol Search (SS), Digit Span (DS), Mazes (MZ). All subtest scores have a mean of 10 and a standard deviation of 3. Index and individual subtest score were included in order to investigate different profiles between the severity groups.

**7.2.3: Procedure**

The pre-injury questionnaires were completed by parents on entry to the study. All standardised measures of intellectual ability (IQ), were administered by a qualified psychologist, on an individual basis, according to test instructions.

**7.2.4: Statistical analysis**

Repeated measures analysis of variance (Severity x Time) were conducted to examine the association between injury severity and intellectual performance across the time points. Tukey’s (HSD) statistic indicated specific group differences. Stepwise Multiple Regression was also conducted in order to examine which variables best predicted outcome on the intellectual measures. For one child with
severe TBI score distributions were unacceptably skewed due to extreme results, and in this instance the scores were windsorized and the child was assigned a score of two standard deviations below the total group mean.

7.3: Results:

Comparison of pre-injury ability

As described in Chapter 6 and Table 7.1 (see below), there was no significant difference between the TBI groups on pre-injury measures, suggesting that post-TBI differences may be attributable to the injury.

Table 7.1: Vineland Adaptive Behavior Scale (VABS) domain scores - (pre-injury)

<table>
<thead>
<tr>
<th>Domains</th>
<th>Mild TBI</th>
<th>Moderate TBI</th>
<th>Severe TBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication M (SD)</td>
<td>109.92 (11.82)</td>
<td>103.90 (14.09)</td>
<td>107.00 (7.73)</td>
</tr>
<tr>
<td>Daily Living Skills M (SD)</td>
<td>99.71 (11.43)</td>
<td>101.03 (15.21)</td>
<td>101.50 (6.69)</td>
</tr>
<tr>
<td>Social Skills (SD)</td>
<td>103.75 (16.00)</td>
<td>104.07 (13.65)</td>
<td>102.50 (11.20)</td>
</tr>
<tr>
<td>Total Adaptive skills (SD)</td>
<td>106.00 (15.52)</td>
<td>103.90 (15.87)</td>
<td>104.64 (8.25)</td>
</tr>
</tbody>
</table>

Intellectual performance

Summary IQ measures:

Figures 7.1-7.3 provide results for the intellectual measures (see Figures 7.1-7.3). Repeated measures ANOVA revealed a significant Severity effect for VIQ ($F(2,67)=4.9$, $p<.05$) and a significant interaction effect ($F(2,134)=5.0$, $p<.01$), where the mild group performed better than the other TBI groups, however the severe group showed some improvement, suggestive of recovery from the acute phase to 24 months post-injury. Similar results were evident for PIQ with significant main effects of Severity ($F(2,67)=6.3$, $p<.01$), Time ($F(2,134)=38.6$, $p<.001$), and a significant interaction effect ($F(2,134)=5.9$, $p<.001$). A dose-response relationship was evident, where the severe TBI group achieved the lowest scores. However, all groups improved over time, with the largest improvement seen by the severe TBI group, suggesting some recovery in this area, in addition to
a possible general practice effect. With regard to FSIQ, results again followed the expected pattern. Analysis revealed a significant main effect of Severity ($F(2,67)=7.2$, $p<.01$), Time ($F(2,134)=19.0$, $p<.001$) and a significant interaction effect ($F(2,134)=7.8$, $p<.001$). Again, the severe TBI group achieved the lowest scores but improved most over time.

![Graph of Verbal IQ](image1)

**Figure 7.1:** Verbal IQ (VIQ) at 0-3, 12 and 24 months post-TBI.

![Graph of Performance IQ](image2)

**Figure 7.2:** Performance IQ (PIQ) at 0-3, 12 & 24 months post-TBI.
Figure 7.3: Full Scale IQ (FSIQ) at 0-3, 12 & 24 months post-TBI.

**Index measures:**

Repeated measures ANOVA was also undertaken to investigate the Index measures (See Figures 7.4-7.7). With regard to VC a dose response relationship was evident. Analysis revealed a significant main effect of Severity ($F(2,66)=3.9$, $p<.05$) and a significant interaction effect ($F(2,132)=4.3$, $p<.01$). As for VIQ, while the severe TBI group performed more poorly than the other TBI groups, they showed the most improvement over the two years, suggesting that both developmental gains and recovery took place over this time span. Performance on PO followed the same pattern as VC. Repeated measures ANOVA revealed a significant main effect of Time ($F(2,132)=13.2$, $p<.001$) and a significant interaction effect ($F(2,132)=4.5$, $p<.01$), where the severe TBI group showed marked improvement from the acute to 12 month period, suggesting substantial recovery during this time.
The FFD factor resulted in a somewhat different pattern, where again a main effect of Severity was evident ($F(2, 66)=3.3$, $p<.05$), and where-by the mild TBI group achieved the highest score. However, the moderate and severe TBI groups performed similarly, suggesting some difficulty with attentional skills following
moderate-severe TBI. When investigating PS a dose response relationship was again clear. Analysis revealed significant main effects of Severity ($F(2, 65)=6.9$, $p<.01$) and Time ($F(2,130)=0.7$, $p<.001$), where all TBI groups showed improvement over time, suggestive of developmental gains over the two years post-injury.

![Graph showing processing speed over time for different TBI severities.](image)

Figure 7.6: Processing Speed (PS) Index at 0-3, 12, & 24 months post-TBI.

![Graph showing freedom from distractibility over time for different TBI severities.](image)

Figure 7.7: Freedom from Distractibility (FFD) Index at 0-3, 12, & 24 months post-TBI.
Specific subtest results:

Repeated measures ANOVA revealed different patterns of ability between the TBI groups on the individual subtest measures (See Table 7.2). With regard to the verbal subtests Information ($F(2,66)=5.2$, $p<.01$), Similarities ($F(2,66)=4.8$, $p<.05$) and Arithmetic ($F(2,66)=3.5$, $p<.05$), a dose response relationship was evident, where the mild TBI group performed better than the moderate and severe TBI groups. There was no significant main effect of Severity for Vocabulary, Comprehension or Digit Span, even though inspection of the data revealed that the mild TBI group again performed at a higher level than the moderate and severe TBI groups on both Vocabulary and Comprehension. Digit Span revealed a different pattern, where again visual inspection of the date indicated a sharp rise in this skill from 12 months onwards for the severe TBI group, where at 12 and 24 months they were performing better than the mild and moderate TBI groups.

The Performance subtests revealed more complex results (See Table 7.3). Results indicated significant main effects for Severity and Time for Coding ($F(2,66)=8.8$, $p<.001$; $F(2,132)=16.2$, $p<.001$), Picture Arrangement ($F(2,66)=3.2$, $p<.05$; $F(2,132)=36.1$, $p<.001$), Block Design ($F(2,66)=3.3$, $p<.05$; $F(2,132)=6.2$, $p<.01$), Object Assembly ($F(2,65)=3.5$, $p<.05$; $F(2,130)=4.6$, $p<.05$), and Symbol Search ($F(2,66)=4.0$, $p<.05$; $F(2,132)=4.6$, $p<.05$). For all these subtests a dose response relationship was evident where the mild group achieved the highest score and the severe TBI group the poorest score, with all groups generally showing improvement for the acute stage to 24 months post-injury, suggesting some practice effect on these tasks. Of interest significant interaction effects were also evident for Block Design ($F(2,132)=2.6$, $p<.05$) and Object Assembly ($F(2,130)=2.9$, $p<.05$) where the severe TBI group showed significant improvement in these areas between the acute and 12 month stages, after which their performance seemed to stabilise.
<table>
<thead>
<tr>
<th>Verbal subtests</th>
<th>Mild TBI (n=24)</th>
<th>Moderate TBI (n=31)</th>
<th>Severe TBI (n=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Information</strong></td>
<td></td>
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</tr>
<tr>
<td>Acute M (SE)</td>
<td>10.4 (0.5)</td>
<td>9.0 (0.4)</td>
<td>6.6 (0.7)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>9.8 (0.5)</td>
<td>8.9 (0.4)</td>
<td>7.4 (0.6)</td>
</tr>
<tr>
<td>24 months M (SE)</td>
<td>9.6 (0.5)</td>
<td>8.9 (0.5)</td>
<td>8.2 (0.7)</td>
</tr>
<tr>
<td><strong>Similarities</strong></td>
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</tr>
<tr>
<td>Acute M (SE)</td>
<td>10.1 (0.6)</td>
<td>9.8 (0.5)</td>
<td>10.3 (0.6)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>8.0 (0.5)</td>
<td>8.4 (0.5)</td>
<td>8.3 (0.5)</td>
</tr>
<tr>
<td>24 months M (SE)</td>
<td>6.7 (0.8)</td>
<td>7.9 (0.7)</td>
<td>8.6 (0.8)</td>
</tr>
<tr>
<td><strong>Arithmetic</strong></td>
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<tr>
<td>Acute M (SE)</td>
<td>11.2 (0.6)</td>
<td>9.4 (0.5)</td>
<td>8.3 (0.8)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>11.0 (0.6)</td>
<td>9.3 (0.5)</td>
<td>9.2 (0.8)</td>
</tr>
<tr>
<td>24 months M (SE)</td>
<td>10.5 (0.6)</td>
<td>9.3 (0.5)</td>
<td>9.0 (0.8)</td>
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<tr>
<td><strong>Vocabulary</strong></td>
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<tr>
<td>Acute M (SE)</td>
<td>8.6 (0.7)</td>
<td>7.1 (0.6)</td>
<td>6.1 (0.9)</td>
</tr>
<tr>
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<td>8.5 (0.6)</td>
<td>7.0 (0.6)</td>
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</tr>
<tr>
<td>24 months M (SE)</td>
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<td>7.5 (0.8)</td>
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<tr>
<td><strong>Comprehension</strong></td>
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<tr>
<td>Acute M (SE)</td>
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<td>8.7 (0.5)</td>
<td>7.8 (0.8)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
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<td>7.9 (0.4)</td>
<td>7.9 (0.7)</td>
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<td>24 months M (SE)</td>
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<td><strong>Digit Span</strong></td>
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<td>9.8 (0.6)</td>
<td>8.8 (0.5)</td>
<td>8.7 (0.8)</td>
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<tr>
<td>12 months M (SE)</td>
<td>9.3 (0.5)</td>
<td>8.5 (0.5)</td>
<td>9.8 (0.7)</td>
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<tr>
<td>24 months M (SE)</td>
<td>10.2 (0.6)</td>
<td>8.9 (0.5)</td>
<td>10.6 (0.7)</td>
</tr>
</tbody>
</table>

*Main effect of Group p<.05; **p<.01; ^ Main effect of Time p<.05; ^^p<.01; # Group x Time Interaction, p<.05

*significant difference between mild and severe TBI groups at T1; **significant difference between moderate and severe TBI groups at T1; ***significant difference between mild and severe TBI groups at T2; †significant difference between mild and moderate TBI groups at T1; ‡significant difference between mild and moderate TBI groups at T3
### Table 7.3: Performance subtest measures

<table>
<thead>
<tr>
<th></th>
<th>Mild TBI</th>
<th>Moderate TBI</th>
<th>Severe TBI</th>
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<tr>
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<td>8.4 (0.9)</td>
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<td>9.2 (0.6)</td>
<td>10.6 (0.9)</td>
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<td>6.3 (0.9)</td>
</tr>
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<td>24 months M (SE)</td>
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<td>9.1 (0.9)</td>
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<td><strong>Object Assembly</strong></td>
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<td>7.4 (0.8)</td>
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<td>8.8 (0.9)</td>
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<td>Acute M (SE)</td>
<td>11.3 (0.7)</td>
<td>11.2 (0.6)</td>
<td>9.9 (0.9)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>10.0 (0.7)</td>
<td>11.4 (0.7)</td>
<td>9.9 (1.0)</td>
</tr>
<tr>
<td>24 months M (SE)</td>
<td>10.0 (0.7)</td>
<td>10.6 (0.6)</td>
<td>9.3 (1.0)</td>
</tr>
</tbody>
</table>

*Main effect of Group p=.05; ***p=.001; ^ Main effect of Time p<.05; ^^p<.01; ^^^p<.001;

# Group x Time Interaction, p<.05

* significant difference between mild and severe TBI groups at T1; ^ significant difference between mild and severe TBI groups at T3; *significant difference between moderate and severe TBI groups at T1; * significant difference between mild and severe TBI groups at T2.
Predictors of intellectual measures:

To investigate predictors of intellectual outcome two years post-injury, stepwise multiple regressions were conducted (see Table 7.4). These analyses investigated the association between the VABS (pre-injury), severity, injury age and SES. None of the variables were highly successful in predicting VIQ, with SES explaining 5% of the variance. PIQ was best predicted by SES and severity, with these variables explaining 12% of the variance, with FIQ also best predicted by SES and severity.

Table 7.4: Predictors of intellectual ability two years post-TBI

<table>
<thead>
<tr>
<th>Predictor</th>
<th>r</th>
<th>r²</th>
<th>F</th>
<th>p</th>
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</thead>
<tbody>
<tr>
<td><strong>Outcome measure</strong></td>
<td></td>
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<tr>
<td>VIQ</td>
<td>SES</td>
<td>0.23</td>
<td>0.05</td>
<td>3.21</td>
</tr>
<tr>
<td>PIQ</td>
<td>SES</td>
<td>0.28</td>
<td>0.08</td>
<td>4.10</td>
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<tr>
<td></td>
<td>Severity</td>
<td>0.35</td>
<td>0.12</td>
<td>3.12</td>
</tr>
<tr>
<td></td>
<td>Injury age</td>
<td>0.40</td>
<td>0.16</td>
<td>2.41</td>
</tr>
<tr>
<td>FIQ</td>
<td>SES</td>
<td>0.29</td>
<td>0.08</td>
<td>5.45</td>
</tr>
<tr>
<td></td>
<td>Severity</td>
<td>0.35</td>
<td>0.12</td>
<td>2.74</td>
</tr>
<tr>
<td></td>
<td>Injury age</td>
<td>0.40</td>
<td>0.16</td>
<td>2.18</td>
</tr>
</tbody>
</table>

7.4: Discussion

Pre-injury ability

Comparison of pre-injury performance on the VABS indicated that the three TBI groups were functioning similarly prior to the injury. This therefore suggests that differences between the groups post-injury are directly related to the injury, rather than to any pre-injury differences.

Intellectual measures

the mild and moderate TBI groups generally performed within the average range, with little change in performance, over the two years post-injury. Alternatively, the severe TBI group performed within the “Low Average” range during this time period, however showing more improvement in comparison to the other TBI groups. This suggests that while VIQ may be less vulnerable following TBI, the severe TBI group appears to present with some recovery in this area, indicating that VIQ scores are affected to some degree by the injury. The severe TBI group proceeded to perform more poorly than the other TBI groups throughout the two year follow-up period.

PIQ showed similar dose-response results, where the mild TBI group performed the best, and the severe TBI group was the most compromised. However, all TBI groups showed some improvement in scores over time, suggesting that repeated exposure to the test materials allowed practice effect to influence outcome on these tasks. Of importance, the severe TBI group showed most change over time (mild TBI=5.5 points; moderate TBI=5.2 points; severe TBI=17 points), indicating that as well as practice effects, the severe TBI group presented with substantial recovery in this area, performing within the “Average” range from 12 months onwards. The results for VIQ and PIQ support those of Fay and colleagues (1993) who reported that mild TBI appears to have minimal significant long-term effects.

FIQ results revealed the same pattern, where the severe TBI group was the most compromised. While the mild and moderate TBI group showed a slight improvement in FIQ from acute to 24 months post-injury (approximately 2 points), the severe TBI group improved by 12 IQ points. Therefore, as reported by other researchers (Chadwick et al., 1981, Jaffe et al., 1992, 1993, 1995), there is firm evidence that severe injury is related to poorer results on FIQ. The severe TBI group also presented with some recovery in all areas, with PIQ and FIQ reaching the “Average” range by 24 months post-injury.
Index and subtest measures

Performance on VC parallels the VIQ outcome, where there is a strong dose-response relationship, with the severe TBI group showing more improvement/recovery in this area, in comparison to the other TBI groups. If one divides PIQ into PO and PS components, both of which are essential to perform appropriately on PIQ tasks, results indicate that the severe TBI group show a marked improvement on PO tasks from acute to 24 months post-injury (functioning similarly to the mild and moderate TBI groups at this stage), with less differential improvement apparent on the PS index over the same time period. These results suggest that it is the greater improvement in the area of PO, rather than a marked increase in processing speed, that may explain the recovery shown for PIQ by the severe TBI group. The FFD factor revealed a different pattern, where the moderate and severe TBI groups were performing similarly at 12 and 24 months post-injury, performing significantly poorer than the mild TBI group. This poorer ability in the attentional area may compromise performance on tasks that require concentration and the ability to maintain attention over a period of time.

The subtests results also reflect the IQ and Index scores. The non significant results on the Vocabulary and Comprehension subtests seem to confirm that TBI has less effect on previously well-learned information. The children enrolled in this study were between 8-12 years at the time of injury and so may have already established a sufficient vocabulary base and an understanding of social situations and rules. In contrast, information is continually acquired and more complex tasks mastered through-out childhood and so it was not surprising to see poorer performance on the Information and Similarities subtests by the severe TBI group. Similarly, there were many more significant differences on the Performance subtests where skills such as speed of processing, organisational ability, problem-solving and dealing with more complex situations are essential if one is to perform well in this area. One would assume that the aforementioned skills also develop through-out childhood, since adults are obviously more skilled in these areas than children, and so an interruption to this development may have affected the efficient acquisition of these skills following moderate-severe TBI. The results tend to
indicate that while the severe TBI group do show some recovery over time, more-so than the moderate and mild groups, they still generally perform poorest in most areas at 24 months post-injury.

**Predictors**

Regression analysis failed to provide definitive information with regard to predictors of intellectual ability two years post-injury. The variables that appeared to have the greatest predictive value were SES and injury severity, suggesting that a child’s pre-injury ‘exposure/environment’, in addition to the severity of injury best predicted outcome in the area of general intelligence. With regard to developmental issues, one might suggest that skills not fully developed prior to an injury (e.g. PIQ which depends on processing speed and problem-solving) may be more susceptible following TBI. However, the regression analysis did not find that age at injury was a significant predictor. This result is likely to be due to the use of standardised tests and narrow age range employed in this study, with the design of the study aiming to minimize the confounding effects of development.

**Conclusions**

In conclusion, consistent with previous research, the present study strongly supports the influence of injury severity on outcome. A dose-response relationship was evident for all tasks, with the mild TBI group performing the best and the severe TBI group the poorest, across the two years post-injury. Further, despite their poorer performance over time, the severe TBI group showed both developmental gains and some recovery in comparison to the mild and moderate groups. In particular, the WISC-111 Index scores provided insight into the areas that showed greatest improvement over time. Verbal Comprehension improved by 5.7 points; PO by 16.8 points, FFD by 7.2 points; and PS by 9.3 points. Results stress the need to continue to monitor these children to investigate which skills continue to show marked improvement, and which skills show poorer development/recovery (e.g. the moderate and severe TBI groups performed similarly on the FFD factor), as these may interfere with and affect educational outcomes. Furthermore, it is important to keep in mind that IQ may not be sensitive
to problems experienced in the classroom, and even by children who have sustained a mild TBI may present difficulties that need to be further delineated and addressed.
Chapter 8

Attentional skills following paediatric traumatic brain injury

8.1: Introduction:
The recovery of attention following paediatric TBI

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

While much TBI literature does not differentiate aspects of attention, this is important in order to understand deficits and implement relevant interventions. Recently, it has been argued that attention is not a unitary process and a number of models have described it as an integrated system, both cognitively and physiologically (Cooley & Morris, 1990; Halperin, 1991; Mirsky et al., 1991; van Zomeren & Brouwer, 1994) involving a number of separate, though not independent components. According to Mirsky and associates (Mirsky et al., 1991) attention can be broken into the following components: (i) Sustained attention or vigilance refers to the capacity to maintain arousal and alertness over time; (ii) selective attention is the ability to select target information while ignoring irrelevant stimuli, and to differentially process simultaneous sources of information; (iii) shifting attention involves the ability to change attentive focus in a flexible and adaptive manner. Speed of processing, or the rate at which activities may be completed, is also incorporated into Mirsky’s system, and considered to underpin the efficiency of the system.
The attentional system is thought to be subsumed by a number of cerebral systems including the brainstem, midbrain structures, temporal, parietal and frontal regions (Mirskey et al., 1991). They argue that each area is related to a specific attentional component. The model suggests that damage or dysfunction to any one of these regions can lead to specific deficits in attentional ability or speed of processing, restricting the efficiency of the whole system. Of importance, it is these areas that subserve attentional and information processing functions, that have been observed to be particularly vulnerable to damage occurring in a closed head injury, therefore it is not surprising that deficits emerge at the acute or later stages (Walsh, 1978).

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

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

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

Despite the importance of attention in this younger age group, only a few studies have been reported. Timmermans and Christensen (1991) investigated 38 TBI children, aged 5 to 16 years, and found evidence for impairments in sustaining attention, with selective attention skills intact. In contrast, Dennis and associates (Dennis et al., 1995) found that children and adolescents with a history of head injury performed poorly on a measure of vigilance and selective attention. Anderson and Pentland (1998) have argued for a pattern of global attentional deficits following head injury sustained in childhood. They studied the attentional profiles of children who had sustained moderate to severe TBI, and found that attentional and information processing deficits persist in the years post injury, with greatest problems in the areas of speed of processing (which may be the deficit underlying poor results on sustained and focused attention tasks) and shifting attention. Interestingly, it is these impaired components of attention and information processing, as well as the ability to sustain attention, that are believed to continue to mature into late childhood and early adolescence (McKay et al., 1994), suggesting that childhood injury may interfere with their efficient development.
Measuring attentional skills

In recent years variations of the Continuous Performance Paradigm (CPT: Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956) have become widely used as measures of attention, especially of sustained attention. The sensitivity of the CPT paradigm to sustained attention is believed to result from such signals being presented rapidly over a lengthy period of time. As such tasks provide no means to correct an error once a response is given, then even brief periods of inattention can be detected (Halperin, 1991). The use of the CPT has several advantages: the task is easy and children quickly learn the requirements of the task; the experimental conditions can be controlled; there is uniformity of presentation; response characteristics such as reaction time and nature of errors can be measured accurately; and it is not influenced by observer bias.

A number of researchers have employed CPT paradigms in the study of attentional function following TBI. Ewing-Cobbs et al. (1998) investigated attentional functions from 5-8 years post-TBI in children aged 0-15 years at the time of injury. They addressed a range of issues including injury severity, age at injury and the vulnerability of skills in a rapid stage of development when disrupted by acquired brain injury. It was found that younger children, irrespective of injury severity, performed more poorly than older children on a task reflecting the sustain construct of Mirsky et al. (1991). With regard to injury severity, scores were reduced following mild, moderate and severe TBI in younger children and following severe TBI in older patients.

Kaufman et al. (1993) investigated attentional functioning in thirty-six mild, moderate and severe TBI children, aged 7-16 years, at six months post TBI. It was concluded that children with severe TBI demonstrated poorer performance on the CPT, in comparison to those with mild and moderate TBI. The authors interpreted their findings as indicating impairments in sustained attention six months post-injury, with magnitude of deficits related to injury severity. However, the design of
the study did not allow for investigation of possible deterioration in performance overtime, which would be expected with presence of sustained attention deficits.

More recently Anderson and Pentland (1998) extended the work of Kaufman et al. (1993), using the CPT paradigm with 22 adolescents who had sustained moderate or severe TBI at least eighteen months prior to testing and 22 healthy age-matched controls. Anderson and Pentland (1998) suggested that a ‘true’ measure of sustained attention would be required to reflect a deterioration in performance, in order to fit the description of sustained attention, that is the ability to maintain attention (and so perform appropriately on a given task) over time. These authors employed a paradigm which divided CPT performance into four blocks (each of five minutes) to determine any fall off in performance with time., based on models suggested by van Zomeren and Brouwer (1994), which argue that to measure specific deficits in sustained attention, there is a need to evaluate changes in performance over time. No such deterioration was found across sequential blocks for children with TBI in comparison to controls, suggesting no clear evidence of depressed sustained attention. However, these findings, as for those of Fenwick and Anderson (in press), did suggest slowed rate of processing for the TBI group, across all blocks.

While CPT paradigms have been useful, further investigation needs to be made into the underlying skills required ( in addition to sustained attention) to perform successfully through-out this task. Such an approach was conducted by Murray, Shum, & McFarland (1992), who used an experimental design to investigate four different stages of information processing: feature extraction and identification, response selection and motor adjustment. These authors found that children who had sustained TBI exhibited specific impairment in response selection and rate of motor execution, with feature extraction and identification intact, conceptualising components of attention to define specific impairments which may interfere with these processes.
The present study aims to map the recovery of components of attention (sustained, selective, shift and speed of processing) over 24 months post-injury, and to identify whether attentional deficits are of a generalised nature or are specific to a particular aspect of attention. The specific hypotheses are as follows:

(A) Injury-related effects:
(i) that moderate and severe TBI is associated with generalised attention and information processing deficits post-injury; (b) some recovery will occur over time, with more deficits in speed of processing and shifting and sustained attention at 24 months post-injury, reflecting the interaction between injury factors and ongoing development.

(B) Development-based effects:
Based on the developmental data from McKay et al. (1994), sustained attention and speed of processing are believed to develop rapidly through late childhood and into adulthood. An insult to the brain during childhood, before the mastery of these skills, is predicted to cause deficits in these domains. It was therefore predicted (i) the performance of children with severe TBI will deteriorate during the CPT task, demonstrating a significant decline in attentional capacity with time on task; (ii) severe TBI children will make more errors of omission, commission and impulsivity throughout the task and so show greater variability in performance, reflecting fluctuations in attentional capacity.

(C) Specific processes of attention
Further experimental manipulations of the CPT were incorporated in order to investigate specific processes which may affect attentional ability. It was predicted that (i) the severe TBI group will perform more poorly on the CPT, even when the task was reduced in length; (ii) performance of TBI groups will be similar when the CPT stimuli were presented at a slower rate; (iii) no significant differences will be identified between severity groups for simple reaction time.
8.2: STUDY 1: Recovery of attention

8.2.1: Method:

8.2.2 Participants

The sample comprised 67 children, 51 male and 16 female. Nine children were deleted respectively, due to missing data. For detailed description of sample refer to Chapter 6.

8.2.3: Measures

Teacher and parent assessment

Rowe Behavioural Rating Inventory: (RBRI: Rowe & Rowe, 1995): Teacher and Parent versions - This questionnaire was completed by teachers (16 items) and parents (20 item), in the acute, 6, 12 and 24 months post-injury. The questionnaire completed during the acute stage reflected the child’s pre-injury characteristics. Both versions included information in the domains of sociability, attention, and restlessness. Raw scores were included in the analyses, with a higher score indicative of poorer performance (See Appendix 1).

Child Assessment


Attentional measures:

Several components of attention were investigated, as outlined in Mirsky’s model (Mirsky et al., 1991).

(i) Sustained attention: The Continuous Performance Task (CPT: modified version of Mirsky et al., 1991) was used to examine the ability to maintain performance over time as well as speed of information processing, during the acute, 6, and 12 months post-TBI. In this computerized task stimulus letters were displayed for a duration of 500 milliseconds with an interstimulus interval of 1.5 seconds. Task duration was 20 minutes, during which time 600 stimuli were presented. Children were initially given a trial run to ensure that they understood the requirements of the
task. Two letters flashed on the screen and the child was given a target letter (e.g. "c") on which to focus. The child was then shown a response box where the yellow "yes" button was to be pressed if a "c" had flashed on the screen, and the blue "no" button if neither of the letters was a "c". Scores employed in the analysis were: (i) **sustained attention**: number of correct responses, number of missed responses; number of commission and omission errors; (ii) **processing speed**: reaction time for correct responses; and number of impulsive responses, where the reaction time was < 200 milliseconds for a response. For each of these variables a total score was obtained. For each of the above variables, during the acute stage, a score for each five minute segment (BLOCKS 1 - 4) of the task was obtained, to enable further investigation of sustained attention.

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

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

8.2.4: Procedure:
Attention measures were conducted at acute, 6, 12 and 24 months post-TBI, on
an individual basis, by a qualified psychologist, as part of the broader test session.

8.2.5: Statistical analysis:
Repeated measures ANCOVA (covarying for injury age) was undertaken to
investigate and compare the recovery of attentional skills for the TBI groups, on
summary measures. To compare attentional performance across the CPT, repeated
measures analysis of variance (Group x Block) was conducted, where performance
was analysed in five minute blocks. Planned contrasts were utilised to ascertain
specific group differences on the repeated measures variables when a significant
Group x Block interaction was evident. For some measures (CPT: number correct,
number of omission and commission errors, number of missed and impulsive
errors), score distributions were unacceptably skewed due to extreme results. In
such instances (3 children in severe TBI group and two children in moderate TBI
group) scores were winsorized and children were assigned a score of two standard
deviations below the total group mean.

8.3: Results

STUDY 1:
ANOVA indicated no significant differences between the groups, for either
teacher or parent versions of the Rowe Behavioural Rating Inventory (Rowe &
Rowe, 1995), with regard to pre-injury status in the areas of Sociability, Attention and Restlessness, suggesting the TBI groups were functioning similarly prior to their injuries.

**Behavioural questionnaires (RBRI):**

**Parent version:** With regard to the Sociability domain, statistical analysis revealed significant main effects of Group ($F(2, 56) = 4.0, p<.05$), Time ($F(3,168) = 9.7, p<.001$) and a significant interaction effect ($F(6,168) = 3.2, p<.01$). The severe TBI group was reported to be most maladaptive, with the sharpest increase in poor social skills evident from acute to 6 months post-injury. Similarly, with regard to the Attention domain, results indicated significant main effects of Group ($F(2, 56) = 4.0, p<.05$), Time ($F(3,168) = 15.0, p<.001$) and a significant interaction effect ($F(6,168) = 7.4, p<.001$). Again, the severe TBI group showed a marked increase in poor attention between the acute and 6 months post-injury period, and remained most inattentive over the 24 month period. The Restlessness domain revealed only a significant Group x Time interaction effect ($F(6,165) = 3.4, p<.01$). Again the severe TBI group appeared the most restless, and by 24 months, while the mild and moderate TBI groups showed a decline in restless behaviour, the severe TBI group continued to show a rise in restlessness. These results indicate a dose-response relationship, where the severe TBI group is showing more maladaptive behaviour in comparison to the mild and moderate TBI groups (See Figures 8.1-8.3).

![Graph](image_url)

**Figure 8.1:** Sociability Domain (parent version) at 0-3, 6, 12, & 24 months post-TBI.
Teacher version: The results from the teacher's responses differed somewhat from the parents' results. When looking at the Sociability domain results indicated a significant main effect for Time ($F(3,159)= 2.9, p<.05$), where the TBI groups
tend to become less maladaptive over time, however, though the results do not reach statistical significance, the teachers rate the moderate TBI group as performing more poorly than the severe TBI group. Again, the Attentive domain showed similar results with a significant main effect of Time (F(3, 162)= 7.3, p<.001). While all TBI groups were generally rated as becoming more inattentive over time, again, visual investigation of the data indicates that the teachers regarded the moderate TBI children to be more inattentive than the severe TBI group. It may be suggested that the severe TBI children may have the assistance of integration aides, who are better able to monitor both their progress and behaviour. With regard to the Restlessness domain ANOVA did not reveal any significant results. However, visual examination of the data suggests that again teachers felt that the moderate TBI group was most restless and the severe TBI group the least restless. In general, these result indicate that teachers were reporting that children who had sustained a moderate TBI were not performing better than those who had sustained a severe TBI, in the behavioural domains investigated (See Figures 8.4-8.6).

![Graph](image)

Figure 8.4: Sociability Domain (Teacher version) at 0-3, 6, 12, & 24 months post-TBI.
(ii) Attentional skills:

**Sustained attention:** Repeated Measures ANCOVA (Group x Time, covarying for age at injury) was conducted for attentional measures. Results on the CPT related to the severity of injury as seen in Table 8.1. With regard to the mean number of correct responses, main effects of Group ($F(2,58) = 7.7, p<.01$) and Time ($F(2,116) = 5.7, p<.01$) were identified, with the severe TBI group achieving fewer
correct responses than the other groups, at all time points. All groups improved on this measure over time, suggesting some recovery of these skills in the first twelve months post-injury, or a possible combination of both recovery and familiarisation with the task. Similarly, with regard to the total number of missed responses, main effects of Group ($F(2,58)=6.2, \ p<.01$) and Time ($F(2,116)=5.4, \ p<.01$) were detected, with the severe TBI group recording more missed responses at all time points post-TBI, but all groups improved over time.

A main effect of Time ($F(2, 116)=3.5, \ p<.05$) was evident for errors of Omission, and a main effect of Group ($F(2, 58)=3.4, \ p<.05$) for errors of Commission. Inspection of the data revealed that all TBI groups made less errors of Omission and Commission over time, with the severe TBI group presenting with the highest number of Commission errors during the acute and 6 monthly stages post-injury. Mean reaction time and impulsive errors showed no evidence of significant group differences or recovery over time, as illustrated in Table 8.1. Of interest, the severe TBI group exhibited a trend to shorter reaction times, possibly reflecting impulsivity, leading to a higher error rate.

Repeated Measures ANOVA (Group x Block) was conducted to examine attentional performance over time (See Figures 8.7-8.12). CPT performances were analysed in terms of four 5 minute blocks, to examine possible decrements in performance from the commencement of the task to the end of the twenty minutes duration. Such investigation was considered to provide an indication of sustained attention. For the mean number of correct responses, the main effects of Group ($F(2,69)=5.3, \ p<.01$), as in the total correct score, and Block ($F(2,69)=14.63, \ p<.01$) were significant. The mild TBI group achieved more correct responses in comparison to the moderate and severe TBI groups, however, all the groups showed some decrement over time, with the severe TBI group also showing largest decrement in performance between the first 5 minutes and the last five minutes of the task. This finding suggests a lesser capacity for sustained attention for the severe TBI group during the acute stage post-injury.
Table 8.1: Sustained Attention: summary scores

<table>
<thead>
<tr>
<th></th>
<th>Mild TBI</th>
<th>Moderate TBI</th>
<th>Severe TBI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n=24</td>
<td>n=28</td>
<td>n=15</td>
</tr>
<tr>
<td><strong>Sustained attention: CPT</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. correct ** ***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute M (SE)</td>
<td>531.4 (18.7)</td>
<td>497.9 (17.2)</td>
<td>422.7 (27.7)</td>
</tr>
<tr>
<td>6 months M (SE)</td>
<td>540.7 (10.6)</td>
<td>525.5 (9.7)</td>
<td>473.5 (15.7)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>551.8 (11.9)</td>
<td>534.1 (11.0)</td>
<td>487.3 (17.7)</td>
</tr>
<tr>
<td><strong>Mean Reaction Time</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute M (SE)</td>
<td>627.3 (27.7)</td>
<td>673.8 (25.6)</td>
<td>596.7 (43.5)</td>
</tr>
<tr>
<td>6 months M (SE)</td>
<td>638.8 (29.8)</td>
<td>620.0 (27.5)</td>
<td>589.6 (46.8)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>647.1 (28.0)</td>
<td>611.1 (25.8)</td>
<td>599.8 (44.0)</td>
</tr>
<tr>
<td><strong>No. missed resp. ** *** b</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute M (SE)</td>
<td>8.7 (3.7)</td>
<td>21.2 (3.4)</td>
<td>30.0 (5.5)</td>
</tr>
<tr>
<td>6 months M (SE)</td>
<td>9.2 (3.4)</td>
<td>14.3 (3.1)</td>
<td>24.9 (5.0)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>5.8 (2.6)</td>
<td>12.5 (2.4)</td>
<td>15.8 (3.8)</td>
</tr>
<tr>
<td><strong>No. of omission errors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute M (SE)</td>
<td>34.8 (4.7)</td>
<td>33.9 (4.3)</td>
<td>54.9 (7.0)</td>
</tr>
<tr>
<td>6 months M (SE)</td>
<td>34.2 (5.2)</td>
<td>37.6 (4.8)</td>
<td>43.9 (7.7)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>23.8 (3.9)</td>
<td>31.7 (3.5)</td>
<td>38.6 (5.7)</td>
</tr>
<tr>
<td><strong>No. of commission errors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute M (SE)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 months M (SE)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>No. impulsive responses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute M (SE)</td>
<td>5.0 (1.2)</td>
<td>6.3 (1.1)</td>
<td>7.7 (1.8)</td>
</tr>
<tr>
<td>6 months M (SE)</td>
<td>4.4 (1.2)</td>
<td>6.3 (1.1)</td>
<td>9.2 (1.7)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>5.1 (1.2)</td>
<td>5.2 (1.1)</td>
<td>8.0 (1.8)</td>
</tr>
</tbody>
</table>

*Main effect of Severity p=.05; **p<.01; ***p=.001; ^ Main effect of Time p<.05; ^^p<.01; ^^^p<.001;

* Group x Time Interaction, p<.05; "p<.01; * significant difference between mild and severe TBI groups at T1; **significant difference between mild and moderate TBI groups at T1; ***significant difference between mild and moderate TBI groups at T3; ****significant difference between mild and severe TBI groups at T3; *significant difference between mild and moderate TBI groups at T2
Similarly, for the number of omission errors, there was a significant effect of Group ($F(2,69)=3.94, p<.05$), as seen in the total score for omission errors, and a main effect for Block ($F(2,69)=10.59, p<.01$). The severe TBI group made more omission errors, with none of the TBI groups presenting with significantly more omission errors toward the end of the task, in comparison to the first five minutes. There was a significant main effect for Block ($F(2,69)=4.39, p<.01$) for the number of commission errors, showing that in general, all TBI groups presented with less errors of commission over time. The number of missed responses differentiated between the groups with significant main effects of Group ($F(2,69)=7.99, p<.01$), Block ($F(2,69)=22.64, p<.01$) and a significant Group x Block interaction effect ($F(2,69)=6.05, p<.01$). The mild TBI group presented with the least number of missed responses, however, all groups missed more responses over time. Planned contrasts revealed that, while there was a significant difference at each Block between the mild and severe TBI groups, the greatest discrepancy was evident in the last five minutes of the task, where the severe TBI group showed the greatest increase in missed responses. The moderate TBI group was also significantly different to the severe TBI group, supporting the prediction of differentially poorer
performance over time, implicating greatest difficulties maintaining attention over time for the severe TBI group.

Figure 8.8: Number of omission errors across the 4 5-minute time blocks.

Figure 8.9: Number of commission errors across the 4 5-minute time blocks.
Figure 8.10: Number of missed responses across the 4-5 minute time blocks.

There was no significant difference for mean reaction time across the TBI groups. However, visual examination of the data indicated that the severe TBI group presented with shortest reaction times, with responses becoming faster in the last ten minutes of the CPT paradigm. Similarly, the number of impulsive errors (reaction time 0-200 milliseconds of the target being seen on the screen) did not differentiate between the groups, however, a trend indicated more errors made by the severe TBI group in comparison to the mild TBI group. Visual inspection of the results suggests that children with severe TBI respond less reliably over time, consistent with reduced cognitive efficiency.
**Selective attention:** For the LCT, there was a significant main effect for Group ($F(2,61)=4.4$, $p<.05$), indicating that the mild TBI group found more targets in the specified time than the other TBI groups. For Trails A, a significant effect of Group ($F(2,63)=9.7$, $p<.001$), Time ($F(3,189)=4.5$, $p<.01$) and a significant Group x Time interaction ($F(6,189)=3.2$, $p<.01$) was detected, with the severe TBI group taking longer to complete the task, but also showing greatest gain (recovery) over time.
The mild TBI group did not record any such gains, supporting an interpretation that improvements associated with severe TBI are due to recovery rather than a practice effect (See Figures 8.13-8.14).

Figure 8.13: Letter Cancellation Test at 0-3, 6, 12, & 24 months post-TBI.

Figure 8.14: Trails A Test at 0-3, 6, 12, & 24 months post-TBI.
**Shifting attention:** Figures 8.15 demonstrates the results for Trails B. Statistical analysis detected significant main effects for Group ($F(2,63)= 3.8 \ p<.05$) and Time ($F(3,189)= 5.6, \ p<.01$), but no significant interaction effect ($F(6,189) = 1.7, \ ns$). The severe TBI group was the slowest to complete the task at all time points, however all groups showed improvement over time, suggesting some practice effect on this task across all groups as well as some recovery for the moderate and severe groups where the discrepancy between initial and 24 month results (moderate = 23 points; severe = 25 points) was much larger than the mild TBI group (mild = 10 points).

![Graph](image)

Figure 8.15: Trails B Test at 0-3, 6, 12, & 24 months post-TBI.

There were significant main effects of Group ($F(2,60)= 7.3, \ p<.01$), and Time ($F(3,180) = 6.4, \ p<.001$) on the CNT Condition 4 (See Figure 8.16). All groups exhibited a trend to quicker completion times at 24 month evaluation (perhaps reflecting some developmental effects), with the mild TBI group performing the quickest and the severe TBI group the slowest. While the results also suggest some practice effect, once again the severe TBI group showed the largest discrepancy (severe TBI=55 points; moderate TBI=33 points; mild TBI= 32 points) between acute and 24 months, suggesting some recovery for this group over time.
8.4: Discussion

The results of the present study provide support for the presence of attentional difficulties both acutely and twenty-four months post-injury following head injury sustained during childhood. These deficits appear to be associated with injury severity, and cannot be explained in terms of pre-injury abilities, demographic factors (See Chapter 6 for further explanation) or behavioural characteristics.

(i) Behavioural measures (RBRI):

Results on the RBRI based on parental responses, indicated a dose-response relationship. That is, from 6 months post-injury onwards, the severe TBI group was showing more maladaptive characteristics with regard to Sociability, Attention and Restlessness. Parental results indicate that by 6 months post-injury, the degree of maladaptive behaviour in the severe TBI group had increased from pre-injury levels, and that maladaptive behaviour continued to the 24 month period. These results suggest that following severe TBI, these behavioural indices of attention may not recover, but may continue to be problematic and interfere with subsequent progress.
Teacher responses differed from those given by parents. However, both teachers and parents showed that behaviour, as characterised by Sociability, Attention and Restlessness, did not appear to improve over time, especially for the moderate and severe TBI groups. Of interest, teachers rated the moderate group as performing more poorly than the mild and severe TBI groups in all domains. A number of possible explanations for these inconsistent findings may be considered. First, unlike parents, in most cases a child’s classroom teacher changes from year to year. This makes it more difficult to interpret results where some of the teachers did not know the child pre-injury and so noted restless behaviour as “normal”, while a teacher who had known a child pre-injury may consider the restless behaviour as “maladaptive” for that child. Second, the perception of whether behaviour is acceptable or not acceptable, will differ between teachers, biasing responses made to particular questions. Third, and most importantly, children who have sustained a severe TBI often have an aide in the classroom. The assistance of an aide may in fact mask the level of maladaptive behaviour that would be present if the child was less supervised. Also, parents and teachers may differ in the behaviour samples they observe. for example, a severe TBI child may be slow and non-active in the classroom and so non-problematic, whereas at home, such behaviour may be considered out of character and problematic for that child. However, of importance, both parent and teacher responses indicate that behavioural difficulties are often present following moderate to severe TBI.

(ii) Attentional measures

Results on the attentional and information processing tasks indicated a dose-response relationship, which appeared to persist during the acute and sub-acute phases post-injury. Both level of competence and recovery patterns varied depending on the specific attentional component being measured. It may be postulated that this variability in recovery may depend on the specific cerebral regions impacted by injury, their level of maturity, and the nature of the damage (e.g. shearing, contusions).
**Sustained attention:** The severe TBI group achieved fewer total correct responses at all time points post injury. However, all groups improved over time, suggesting some recovery of this skill as generalised effects of head injury diminish. In fact, the severe TBI group showed most improvement and the mild TBI group the least improvement, demonstrating that the improvement seen is likely to be due to recovery rather than familiarisation with the task.

Contrary to expectations from adult literature, there were no statistically significant differences between groups for simple speed of response, thus failing to support an argument that slowed response rate underpins attentional deficits post-TBI in children. Similarly, no group differences were detected for impulsive errors, however there was a trend for the severe TBI group to do more poorly in this area. With regard to missed responses and commission errors, again a dose-response relationship was evident, where the mild TBI group performed best, and the severe TBI group the poorest, with all groups showing some improvement over time. In most cases the severe TBI group showed the largest increment between acute and 12 month results, suggesting both a general practice effect as well as recovery for this most compromised group. Omission responses demonstrated the same pattern, with all groups improving over time, but the severe TBI group performing the poorest at 12 months post-injury. Such findings are consistent with those of Kaufman and associates (Kaufman et al., 1993) and Timmermans and Christensen (1991), who also showed that children with a head injury exhibited significant difficulties sustaining attention, with these difficulties reflected in poorer performance on the various measures of the CPT.

Examination of performance over the four sequential blocks of the CPT revealed both Group and Block effects. That is, the severe TBI group presented with the least number correct, but all groups performed more poorly over time. Of importance, the severe TBI group presented with the largest discrepancy between the first five minutes and the last five minutes of the task, again reflecting a particular difficulty maintaining performance over time. For missed responses, an interaction effect was also detected, suggesting that the more severe the injury, the
poorer the child’s capacity to sustain attention over time (especially the last five minutes of the task). Such findings are consistent with a number of previous studies (Timmermans & Christensen, 1991; Kaufman et al., 1993) where children with TBI demonstrate significant difficulties sustaining attention.

As with total correct responses, severity effects were identified for the number of omission errors, with a similar trend evident for the number of commission errors. It may be suggested that the severe TBI group present with instances of inattention, finding it difficult to consistently process the information efficiently and to inhibit incorrect responses to particular stimuli. Analysis of error patterns over the four time blocks provided further support for this interpretation, with the severe TBI group recording the most omission and commission errors in each five minute segment. While the mild and moderate TBI groups had a similar number of omission and commission errors across the four time segments, the severe TBI group presented with least omission and commission errors in the last five minutes of the task in comparison to the commencement of the task. Analysis of overall error patterns suggests that this may be due to an increase in missed responses, rather than a reflection of more accurate responses.

With regard to processing, there were no significant results for either mean reaction time or the number of impulsive errors (responses < 200 milliseconds) between the TBI groups. However, visual inspection of the data suggests that the severe TBI group tended to respond more quickly (based on reaction times for correct responses), and made more impulsive errors in comparison to the mild and moderate TBI groups. It may be suggested that impulsive errors may in fact be ‘late’ responses (a slow response from the previous stimuli), however, analysis of the data did not support this interpretation. These findings, while not reaching statistical significance, are inconsistent with literature which suggests that slowed response rate underpins attentional deficits post-TBI. The pattern of results may reflect the ‘acute’ deficits of the whole sample, where the mild and moderate TBI groups are exhibiting slower reaction times in the acute phase, but which may show recovery over time, stressing the importance of documenting recovery over time.
When further considering reaction time over the four time segments, as stated above, the results indicated no significant main effects of Group or Time. However, the trend for each of the five minute segments revealed that the severe TBI group appeared to responded more quickly than the other TBI groups, again suggesting that on simple reaction time tasks the severe TBI group do not present with slowed processing speed. With regard to the number of impulsive errors (reaction time < 200 milliseconds), visual inspection of the data, as there were no significant effects, suggested that while the severe TBI children responded more quickly, they did not make significantly more impulsive responses compared to the mild and moderate TBI groups.

Selective attention: As for measures of sustained attention, findings suggest that injury severity is related to outcome in this area of attention. Results on Trails A support the possibility of visual selective attention and information processing deficits as the severe TBI group took longest to complete this task at all time points. However, the severe TBI group showed substantial improvement over time. Results on the LCT were also in the expected direction, with significant differences between the groups. That is, the mild head injured group achieved highest number correct in one minute and the severe group achieved fewest number correct. Of importance, this measure is dependent on visuo-motor speed and coordination, so it may be interpreted that the severe group has poorer selective attention, slowed visuo-motor processing or a combination of these. Such results do provide partial support for findings in the adult literature where reduced speed of information processing has been implicated as a confounder on tasks measuring attentional skills (Ponsford and Kinsella, 1992; Stuss et al, 1989; Anderson and Pentland, 1998). However, our results suggest that these problems are specific to visuo-motor performance with simple processing speed (i.e., reaction time) intact.

Shifting attention: Children with a moderate or severe TBI demonstrated a reduced ability to shift attentive focus effectively, as seen by results on the Trails B task. The moderate and severe TBI groups completed tasks requiring a shift in
attention more slowly, with both groups showing much improvement over time. It is difficult to determine whether the deficiency is one of shifting attention, or whether there is poor ability to shift attention in conjunction with slowed visuo-motor processing. Such an interpretation is consistent with Wood’s argument, where he stated that head injury may limit attentional capacity, it can reduce the extent to which attention can be divided across stimuli and so may affect one’s ability to “shift” their mode of thinking, resulting in slower and even less reliable processing of information (Wood, 1988). Significant differences were detected on the CNT (condition 4) indicating that while all TBI groups improved over time, the severe TBI group showed the most substantial improvement, however still performing below the level of the other groups. This task does not involve a visuo-motor component, but rather a verbal response, suggesting that children who sustain a significant injury present with an exacerbation of difficulties as both shifting attention and slowed processing, especially when a visuomotor component is also required, are compromised.

Summary and conclusions

Moderate and severe TBI during childhood results in specific attention and information processing deficits up to 24 months post-injury. Not all areas of attention are affected similarly, with factors including the nature of the task (e.g., visuo-motor tasks in comparison to computerised reaction time tasks), task complexity and speed requirements affecting outcome. These results provide partial support for findings from the adult literature where deficits for speed of processing are reported (Murray et al., 1992; Ponsford & Kinsella, 1992). However, while adult head injury is thought to be a general disruption to attention and information processing (Van Zomeren & Brouwer, 1994), this current study revealed that deficits seen following severe TBI are not generalized, with simple motor speed relatively intact (inconsistent with Anderson & Pentland, 1998; Anderson & Fenwick, 1999, who found a slowed rate of processing across all Blocks), but visuo-motor processing more impaired, suggesting that speed of processing deficits may be more evident for more demanding tasks. In addition to deficits identified in adults, evidence for impairments in sustained attention was
also found in the paediatric population, with these deficits most evident following severe TBI. These results may reflect developmental characteristics of the group, that is, that sustained attention is immature at the time of the injury (McKay et al., 1994) and so is more vulnerable and at a greater risk following childhood TBI.

With respect to selective and shift measures, dose related deficits were identified, however it is difficult to separate attentional effects from visuo-motor processing requirements in these domains. Future research may be directed towards more accurate delineation of these skills. The more widespread attentional difficulties seen in childhood TBI may reflect the relatively immature state of the central nervous system at the time of injury. Thus attentional skills not developed (e.g., sustained, shift and processing speed) may be more vulnerable and less likely to develop normally and so cumulative deficits may also result after TBI in childhood (McKay et al., 1994).

In conclusion, the present study suggests that attentional deficits do occur and persist following a closed head injury, with degree of impairment related to injury severity. Children sustaining a severe TBI performed more slowly on a range of tasks that were timed and required visuo-motor skills. These children also demonstrated difficulty in the area of sustained attention. It is important to note that children with mild TBI performed relatively well on all attentional measures, suggesting minimal impact of injury for these children. The variability of test results reflect the difficulties in making accurate interpretations on these multi-determined measures. It is important to look closely at measures of attention in order to ascertain whether these tasks a purely measuring what they pertain to measure, or whether each task is in fact measuring a number of skills some of which recover more quickly than others following a closed head injury. It has been argued that deficits in attention and speed of processing may impede future learning and acquisition of knowledge, resulting in current and cumulative deficits, and so it is important to gain a better understanding of the recovery of these skills following childhood insult.
8.5: STUDY 2: Analysis of specific components of attention:

8.5.1: Method:

8.5.2: Participants:

The sample comprised 67 children, 51 male and 16 female. Nine children were deleted respectively, due to missing data. For detailed description of sample refer to Chapter 6.

8.5.3: Measures:

At two years post-TBI, the CPT paradigm was manipulated to further investigate aspects of attention and information processing.

Condition 1: The original CPT was administered, however the duration was reduced to 6 minutes. The scores employed were percentage correct and mean reaction time for the number correct. This allowed the comparison of the TBI groups on a shortened version of the original CPT, to determine whether the length of the task influenced the results.

Condition 2: The original CPT was administered, but with an increase in the interstimulus interval to 3000 milliseconds (the original was 1500 milliseconds). The task was of 6 minutes duration and percentage correct and mean reaction time for the number correct were the scores used in analyses. Experiment 2 was included as it would assist in determining whether processing speed was problematic for the severe TBI group, or whether sustained attention was a deficit, as the task was much slower than Experiment 1.

Condition 3: The original CPT was administered, however for this experimental manipulation, only one letter flashed on the screen. The task was of 6 minutes duration and scores employed were percentage correct and mean reaction time for the number correct. Experiment 3 reduced the 'selective attention' component of the test, as no scanning across letters was required, with only a simple "Yes" or "No" response required.
8.5.4: Procedure:

Attention measures were conducted at acute, 6, 12 and 24 months post-TBI, on an individual basis, by a qualified psychologist, as part of the broader test session.

8.5.5: Statistical analysis

Analysis of covariance (covarying for age at injury) was conducted to examine any group difference for Conditions 1, 2, and 3. Post-hoc analysis was used to identify any specific group differences on the measures analysed. For two subjects score distributions were unacceptably skewed, indicating very poor performances. One child had sustained a severe TBI and he was assigned a score of 2 standard deviations below the total group mean. The other child belonged to the mild TBI group and his score was windsorised and assigned a score of 2 standard deviations below the mild TBI group mean.

8.6: Results:

As mentioned previously, 3 experimental manipulations of the CPT were investigated. See Table 8.2 below for a further description of the three Conditions:

Table 8.2. Experimental manipulations of CPT paradigm employed in study

<table>
<thead>
<tr>
<th>Condition</th>
<th>Total task duration</th>
<th>Interstimulus interval</th>
<th>Stimulus presentation</th>
<th>Stimulus choices</th>
<th>Total stimuli presented</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>20 mins</td>
<td>1500 ms.</td>
<td>500 ms.</td>
<td>2</td>
<td>600</td>
</tr>
<tr>
<td>1</td>
<td>6 mins.</td>
<td>1500 ms.</td>
<td>500 ms.</td>
<td>2</td>
<td>180</td>
</tr>
<tr>
<td>2</td>
<td>6 mins.</td>
<td>3000 ms.</td>
<td>500 ms.</td>
<td>2</td>
<td>103</td>
</tr>
<tr>
<td>3</td>
<td>6 mins.</td>
<td>1500 ms.</td>
<td>500 ms.</td>
<td>1</td>
<td>103</td>
</tr>
</tbody>
</table>

CPT experimental variables:

With regard to percentage correct for Condition 1, ANCOVA revealed a significant group difference (F(2, 65)=4.9, p<.05). Post-hoc analysis that the significant difference was between the mild and severe TBI groups. There was no
significant difference between the TBI groups with regard to Conditions 2 and 3, suggesting that the severe TBI group performed equally well on these tasks when compared to the mild and moderate groups. With regard to mean reaction time for the number correct, there was no significant difference between the TBI groups on Conditions 1 and 3, with a significant difference for Experiment 2 (F(2,63)=5.4, p<.01) where the severe TBI group responded significantly more quickly that the mild TBI group (See Table 8.3).

Table 8.3: Results for Conditions 1,2 & 3

<table>
<thead>
<tr>
<th></th>
<th>Mild TBI</th>
<th>Moderate TBI</th>
<th>Severe TBI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n=24</td>
<td>n=31</td>
<td>n=14</td>
</tr>
<tr>
<td>CPT Attention variables:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experiment 1: % correct M (SE)</td>
<td>94.3 (1.5)</td>
<td>92.1 (1.3)</td>
<td>86.6 (2.0)</td>
</tr>
<tr>
<td>Mean reaction time no. correct M (SE)</td>
<td>619.1 (25.0)</td>
<td>569.0 (22.0)</td>
<td>555.4 (34.8)</td>
</tr>
<tr>
<td>Experiment 2: % correct M (SE)</td>
<td>95.7 (1.5)</td>
<td>92.2 (1.3)</td>
<td>90.6 (2.0)</td>
</tr>
<tr>
<td>Mean reaction time no. correct ** M (SE)</td>
<td>739.9 (33.2)</td>
<td>644.6 (29.2)</td>
<td>560.0 (46.3)</td>
</tr>
<tr>
<td>Experiment 3: % correct M(SE)</td>
<td>95.4 (1.9)</td>
<td>92.6 (1.7)</td>
<td>90.9 (2.6)</td>
</tr>
<tr>
<td>Mean reaction time no. correct M (SE)</td>
<td>539.5 (27.3)</td>
<td>501.2 (24.0)</td>
<td>490.1 (38.0)</td>
</tr>
</tbody>
</table>

* p<.05; ** p<.01
'significant difference between mild and severe TBI groups

8.7: Discussion

Condition 1:

Statistical analysis revealed a significant difference between the mild and severe TBI groups on Condition 1. During this experimental task, the children were administered the original CPT task (see Study 1), the difference being that the 20 minute task was reduced to 6 minutes, in order to make it comparable to Conditions 2 and 3. The results revealed that even when the task was reduced from 20 minutes to 6 minutes, the severe TBI group still achieved fewer correct responses when compared to the mild and moderate groups. These results suggest that their
performance was not purely influenced by an inability to sustain attention (as seen in Study 1), since the task was relatively shorter than the original task, but that another factor was making the task difficult for the severe closed head-injured group.

**Condition 2:**

There was no significant difference between the groups for Condition 2. This task differed from Experiment 1 in that the inter-stimulus interval was doubled to 3000 milliseconds, making the flashing of the stimuli much slower. These results suggest that when the severe TBI group are given more time to process the information, that is respond to the stimuli and prepare for the next stimuli to appear on the screen, then they are able to perform comparably to the mild and moderate TBI groups. This further suggests that that it may be the complexity and demands introduced by one stimuli quickly being followed by the next stimuli, that is problematic for the severe TBI group. These findings support Fenwick and Anderson (in press), where a slowed rate of processing was seen for the TBI group across all blocks, suggesting that slowed rate of processing may be a crucial factor underlying performance.

**Condition 3:**

Condition 3 was included as a simple measure of reaction time, where the CPT task was the same as that in Condition 1, but only one letter was flashing on the screen. This experimental condition was included to determine whether simple reaction time differentiated between the groups, as this could then confound results in Conditions 1 and 2. Results revealed no significant difference between the groups on this simple measure of reaction time. Since the rate of stimulus presentation and the inter-stimulus interval were as in Condition 1, these results further suggest that it is not just the complexity/speed of one stimuli quickly following a previous stimuli, but also the decision-making component (was a target letter present?) that makes the task demands in Condition 1 difficult for the severe TBI group.
Summary and conclusions:

Previous results have indicated that the severe TBI group present with a difficulty in sustained attention, specifically seen when there was deterioration in performance over the 20 minute task.

Results from Conditions 1, 2, and 3 give further insight into attentional performance following TBI. Experiment 3 revealed that, for simple reaction time (responding to one letter flashing), the TBI groups performed similarly, indicating that performance on this simple task did not differentiate the groups. Similarly, results from Condition 2 suggested that when the inter-stimulus interval is longer, giving the TBI groups more time to process the information and prepare for the next stimuli, there was no significant difference between them. However, the severe TBI performed significantly more poorly that the other TBI groups in Condition 1.

Since the groups performed similarly on Experiments 2 and 3, it may be deduced that the length of the inter-stimulus interval and the decision-making component required to decide whether a target letter was presented, were the differentiating factors between the groups. The trend was for the groups to respond quicker (mean reaction time for percentage correct) in all experimental conditions, perhaps this tendency to respond quicker on this more demanding task (Condition 1), led to a detriment in performance, with more errors made. Perhaps during Condition 1 the severe TBI group was overwhelmed by the demands of the task and so just pressed the response box indiscriminately. Therefore, regardless of how quickly the severe TBI pressed the response box (they were the quickest), it appeared that it was the length of the inter-stimulus-interval which affected whether the given response was correct. Perhaps boredom when waiting for the stimuli in Condition 2 led to led to quicker responses as the stimuli were presented.

In conclusion, while the severe TBI group presented with a sustained attention difficulty, this may have been confounded by an inability to ‘keep up’ with the demands of the task for Experiment 1, therefore becoming overwhelmed, and perhaps fatigued over time. It is important that these factors are taken into consideration when preparing remedial programs/interventions for these children
post-TBI. Future work is necessary to further investigate these issues, perhaps by presenting Experiment 2 as a twenty minute task, and then investigating whether performance deteriorates over time. If this is the case then the evidence for a sustained attention problem is stronger, suggesting both a sustained attention and speed of processing difficulty, if this is not the case, then the complexity of task demands appears to influence performance.

8.8: General Conclusions:

The different components of Chapter 8 have highlighted the need to use experimental designs in order to better understand the deficiencies faced following TBI in children. Initially it appeared that the severe TBI group responded quickly on the CPT task, suggesting that processing speed was intact. However, further analysis using experimental paradigms revealed that in fact processing speed ( coping with a demanding task that required both speed and accuracy) with an added decision-making component, made the task too overwhelming for the severe TBI group, resulting in deficient performance across a number of skill areas.
Chapter 9

Recovery in memory function following traumatic brain injury in children.

9.1: Introduction:

Memory impairment in the acute and later stages of recovery from TBI can lead to serious handicaps in children who are required to register, learn and retrieve information in day-to-day situations such as the classroom. While a number of studies report impairments in cognitive skills, as measured by tests of intellectual functioning and academic achievement (Brink, Garrett, Hale, Woo-Sam, & Nickel, 1970; Costeff, Grosswasser, & Goldstein, 1990; Chadwick, Rutter, Shaffer, & Shroud, 1981; Ewing-Cobbs, Miner, Fletcher, & Levin, 1989; Jaffe, Polissar, Fay, & Liao, 1995; Ewing-Cobbs et al., 1997), only a handful of studies have investigated specific skills such as memory functioning, which may be underlying the depressed performances of these children (Dikeman, Tenkin, McLean, Wyler, & Machamer, 1987; Donders, 1993; Levin & Eisenberg, 1979; Max, Roberts, Koele, Lindgren, Robin, Arndt, Smith, JR., & Sato, 1999; Pressley & Schneider, 1997), and which may be crucial for future normal development.

Indices of injury severity such as initial GCS, duration of coma and the integrity of ocular responses have all been found to be strongly associated with memory problems following TBI in adults (Dikeman et al., 1987). While such associations suggest that memory problems are due to characteristic patterns of subcortical and frontal pathology observed following TBI, it is also possible that temporal lobe disruption may play a role. Due to their position within the skull, and the mechanics involved in closed head injury, the temporal lobes may suffer contusion or laceration, with resultant memory deficits reflecting focal temporal pathology, as well as the secondary effects of attentional and executive impairments. Despite the likely vulnerability of the temporal lobes to TBI, their importance for storing and consolidating information, and the evidence of ongoing development of these regions through childhood (Baron, Fennell, & Voeller, 1996), the impact of childhood TBI on memory remains poorly understood.
Current models of memory describe multicomponent systems, where information is registered from the environment, encoded and stored, to be available for later retrieval (e.g. Baddeley, 1990; Cowan, 1995). Most theories argue for an 'active' or 'working' model, where the memory system can direct attention, implement strategies (e.g. rehearsal) and control retrieval. It is further argued that these various aspects of memory are subsumed by a number of cerebral areas, including temporal lobes, basal ganglia and frontal regions, which work together to form an integrated functional system (Baddeley, 1990; Columbo & Gross, 1994; Cowan, 1995). Memory skills develop through childhood, as these cerebral regions mature (Bjorklund, 1989; Siegler, 1991), and so may be particularly susceptible to disruption due to TBI.

One of the earliest studies examining the relationship between TBI and memory skills was conducted by Levin and Eisenberg (1979) who investigated children with a history of TBI, aged 6-18 years, categorised according to duration of coma. These authors identified deficits on the two tests of memory function employed in the study, verbal learning and visual recognition. This group (Levin, Eisenberg, Wigg, & Kobayashi, 1982; Levin et al., 1988), later extended their findings to show that younger children were more impaired on visual recognition tasks than on verbal learning tasks, and suggested that developmental factors may be important in determining the nature of memory deficits following TBI in childhood. They postulated that visual recognition memory is established early in life, whereas verbal memory skills undergo continued development into adolescence. Thus visual memory skills will be more impaired in the younger age group, where these skills are still developing. In contrast, a deficit in verbal learning would not be evident until a child was at an age when this skill would normally emerge.

More recent studies have investigated whether TBI in childhood results in global or specific memory impairments. Donders (1993) administered tasks tapping both verbal and visual recall to children with TBI of varying severity. He found no difference with respect to injury severity for verbal recall, however, children with severe TBI performed more poorly for visual recall. While visual recall remained
stable post-injury, verbal recall was noted to deteriorate in all groups. Similarly, a
trend for deterioration of memory function over time, where severely injured
children achieved more impaired memory scores 12 month post-TBI than
immediately post-injury was also reported, suggesting ‘emerging deficits’ following
childhood brain injury (Anderson et al., 1997; Anderson et al., 1999, Anderson et
al., 2000).

Yeates, Blumenstein, Patterson, and Delis (1995), using the California Verbal
Learning Test, found that children with mild and moderate injuries performed as
well as controls on learning trials, demonstrated intact recognition memory, but
recalled fewer words after a delay period. In contrast, children with severe TBI
showed deficits in all areas. Harris (1996) investigated verbal rehearsal and its
association with memory skills in more depth. Nine children (mean age of 11.4
years) were compared to control subjects on an overt rehearsal free recall task.
Subjects were shown a series of items and were instructed to ‘think aloud’
following the presentation of each item to be remembered. Qualitative analyses
suggested that the severe TBI group presented with impaired verbal recall and an
inefficient use of a passive rehearsal strategy, while mild and moderately injured
children used an active rehearsal strategy. Furthermore, the severe TBI group was
found to use mainly simple rehearsal strategies, rather than more efficient and
elaborate strategies. As a whole, TBI children were less able to modify their
rehearsal strategies, were limited in the use of metamemory and had limited
awareness of their memory skills.

Farmer, Haut, Williams, Johnstone, and Kirk (1999) report memory deficits are
related to injury severity as well as to the demands of the memory task. Using the
Wide Range Assessment of Memory and Learning, they demonstrated that children
with mild-moderate injuries performed similarly to control children, while those
with severe TBI achieved poor scores on global indices of visual memory, learning
and global memory function. While the severe TBI group showed impaired
spontaneous recall, they performed no differently from controls on recognition
measures, suggesting a difficulty in spontaneous retrieval, rather than an encoding
difficulty. Further, children had difficulty with delayed recall only if they showed initial encoding problems, a conclusion also reported by Roman et al., (1998).

Research conducted to date has consistently identified memory problems following severe TBI in childhood. In contrast, there is little agreement with respect to the nature of these problems, or their pattern of recovery/development post-injury, with the majority of studies both retrospective and cross-sectional. The aim of the present study was to extend existing knowledge by: (i) mapping the recovery of memory skills over the twenty-four months post-TBI; and (ii) examining a range of memory components in order to establish whether generalized memory problems are evident, or whether problems are modality or task-specific. Based on the available paediatric literature, it was predicted that: (i) a dose-response relationship exists between injury severity and memory deficit, with more severe TBI associated with greater memory impairment and poorer recovery; and (ii) differences in memory function associated with injury severity will be more pronounced on more complex memory tasks. As the age at injury and age at testing were relatively restricted in this study (age at injury: 8-12 years), it was hypothesized that the modality-specific effects present in other studies, with wider age ranges, would not be identified.

9.2: Method:

9.2.1: Participants

The sample comprised 68 children who had sustained a documented TBI, with six children from the total sample not included due to missing data. Of these children, 51 were male and 17 were female. Inclusion and exclusion criteria and severity categorisation as outlined in Chapter 6.

9.2.2: Measures

Child Assessment:

Memory measures:

Immediate memory: (a) Digits Forward (DF: Wechsler, 1991): A test of immediate memory for auditory-verbal material, where children are required to
repeat strings of digits of increasing length. At each difficulty level, two digit strings are presented. The score indicates the maximum number of digits repeated correctly; and (b) Block Span (BS: Milner, 1971): A test of short-term visual memory, involving the presentation of an array of nine identical blocks, where children are required to tap a sequence of blocks of increasing length as demonstrated by the examiner. Two different sequences are presented at each difficulty level. The score indicates the maximum number of blocks tapped correctly.

**Short-term memory/encoding:** (a) Luria Short Stories (LSS: Anderson & Lajoie, 1996): This is a measure of short-term verbal memory, requiring children to recall stories. Two stories, each comprising 21 content items, are read to the child. After each story, the child is instructed to retell the story in his or her own words. Recall (the number of correct items recalled) is summed across the two stories, with a maximum possible score of 42 items; and (b) Complex Figure of Rey, recall (CFR: Rey, 1941): Children were asked to draw, from memory, the Complex Figure of Rey, which they had copied approximately 3 minutes before. A recall score was obtained, using the protocol described by Spreen and Strauss (1991).

**Multi-trial learning:** (a) Verbal Learning Test (Wide Range Assessment of Memory and Learning, (WRAML): Sheslow & Adams, 1990): This task requires the child to learn a list of 16 unrelated words, over 4 consecutive trials. The word list is read aloud before each trial and each child is asked to recall as many words as possible, in any order. The number of words recalled over the 4 trials is summed and a standardised score is obtained. A delayed trial is also administered and the number correct is recorded; and (b) Visual Learning Test (WRAML): This measures one's capacity to learn the spatial locations of fourteen designs, over 4 consecutive trials. Children are asked to remember the location of as many designs as they can. The number of designs recalled over the 4 trials is summed and a standardised score is obtained. A delayed trial is also administered and the number correct is recorded.
9.2.3: Procedure
Memory tests were administered by a qualified psychologist during the acute, 6, 12 and 24 months post-injury.

9.2.4: Statistical analysis
Repeated measures ANOVA (Severity x Time) was conducted to examine the association between injury severity and test performance across the time points. Age at injury was used as a covariate for non standardised measures. For the Verbal Learning and the Visual Learning Test, repeated measures analysis also investigated performance on trials 1-4 within each time point. (acute, 6, 12 and 24 months post-injury), in order to visualise how the TBI groups were performing during the task, rather than obtaining only an overall score. Stepwise Multiple Regression was also conducted in order to examine which variables best predicted outcome in the memory area. For some measures, score distributions were unacceptably skewed due to extreme results. In such instances scores were windsorized and the child was assigned a score of two standard deviations below the total group mean.

9.3: Results:
Immediate memory
Results for immediate memory measures are seen in Table 9.1 (see Table 9.1). Repeated measures ANOVA revealed no significant main effects of Severity ($F(2,62)=0.7$, ns) or Time ($F(3,186)=0.1$, ns) on the DS task. All groups showed slight, non-significant improvement over time, probably indicating expected small developmental gains. With regard to the immediate visual memory task (BS), repeated measures ANOVA revealed a significant main effect of Severity ($F(2,62)=3.3$, $p<.05$), but no significant Time effect ($F(3,186)=1.0$, ns). While all TBI groups performed similarly on BS, the severe TBI group scored more slightly more poorly when compared to the other TBI groups. Overall, these results suggest that on these more simple and immediate memory tasks, in both the acute and post-injury stages, the TBI groups perform similarly.
Table 9.1: Immediate memory results

<table>
<thead>
<tr>
<th></th>
<th>Mild TBI</th>
<th>Moderate TBI</th>
<th>Severe TBI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Immediate memory:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute M (SE)</td>
<td>5.6 (0.2)</td>
<td>5.2 (0.2)</td>
<td>5.1 (0.3)</td>
</tr>
<tr>
<td>6 months M (SE)</td>
<td>5.7 (0.3)</td>
<td>5.5 (0.2)</td>
<td>5.5 (0.4)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>5.9 (0.2)</td>
<td>5.8 (0.2)</td>
<td>5.8 (0.4)</td>
</tr>
<tr>
<td>24 months M (SE)</td>
<td>6.1 (0.2)</td>
<td>5.8 (0.2)</td>
<td>5.8 (0.4)</td>
</tr>
<tr>
<td>BS *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute M (SE)</td>
<td>5.3 (0.2)</td>
<td>5.4 (0.2)</td>
<td>4.6 (0.3)</td>
</tr>
<tr>
<td>6 months M (SE)</td>
<td>5.5 (0.2)</td>
<td>5.1 (0.2)</td>
<td>5.1 (0.2)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>5.4 (0.2)</td>
<td>5.5 (0.1)</td>
<td>5.1 (0.2)</td>
</tr>
<tr>
<td>24 months M (SE)</td>
<td>5.6 (0.2)</td>
<td>5.6 (0.2)</td>
<td>5.2 (0.2)</td>
</tr>
</tbody>
</table>

Main effect of Group: * p<.05

**Short-term memory/encoding**

A main effect of Severity ($F(2,63)=3.5$, ns) was evident between the TBI groups for performance on story recall tasks (LSS), with children who sustained a severe TBI performing more poorly. Analysis also revealed a significant effect of Time ($F(3,189)=4.5$, p<.01), where all groups showed some fluctuations, but generally improved over time, suggesting practice effects, as some children may have recalled the stories from previous exposures.

Analysis of recall of the CFR identified main effects of Severity ($F(2,63)=4.2$, p<.05). These results followed the same pattern as those seen for LSS, where mild TBI was associated with best recall, and all groups performed better over time. There was a slightly greater improvement for the severe TBI group from acute to 24 month assessment (mild TBI= 5.7 points; moderate TBI= 7.4 points; severe TBI= 9.6 points) possibly reflecting a practice effect for all groups and some recovery for the severe TBI group. (See Table 9.2 for LSS and CFR results).
Table 9.2: Short-term memory/encoding results

<table>
<thead>
<tr>
<th>Short-term memory/encoding</th>
<th>Mild TBI</th>
<th>Moderate TBI</th>
<th>Severe TBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSS- Total * ^ a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute M (SE)</td>
<td>24.1 (1.4)</td>
<td>23.4 (1.2)</td>
<td>19.9 (1.8)</td>
</tr>
<tr>
<td>6 months M (SE)</td>
<td>26.8 (1.2)</td>
<td>24.1 (1.1)</td>
<td>22.0 (1.6)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>27.9 (0.9)</td>
<td>27.1 (0.8)</td>
<td>26.0 (1.2)</td>
</tr>
<tr>
<td>24 months M (SE)</td>
<td>28.4 (1.0)</td>
<td>26.4 (1.0)</td>
<td>23.7 (1.4)</td>
</tr>
<tr>
<td>CFR * b c</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute M (SE)</td>
<td>17.3 (1.3)</td>
<td>13.9 (1.2)</td>
<td>10.3 (1.8)</td>
</tr>
<tr>
<td>6 months M (SE)</td>
<td>20.7 (1.2)</td>
<td>18.1 (1.1)</td>
<td>14.7 (1.7)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>22.4 (1.4)</td>
<td>21.8 (1.0)</td>
<td>19.2 (1.5)</td>
</tr>
<tr>
<td>24 months M (SE)</td>
<td>23.0 (1.1)</td>
<td>21.3 (1.1)</td>
<td>19.9 (1.6)</td>
</tr>
</tbody>
</table>

Main effect of Group: * p<.05; Main effect of Time: * p<.01; ^ significant difference between mild and severe TBI groups at T4; b significant difference between mild and severe TBI groups at T1; c significant difference between mild and severe TBI groups at T2.

Multi-trial learning

See Table 9.3 for all results for the Verbal and Visual Learning tests. For the Verbal Learning Test, repeated Measures ANOVA revealed significant main effects of Severity (F(2,64)=8.1, p<.01), and Time (F(3,192)=43.4, p<.001) for the overall standard score. These results indicate a dose-response relationship, where the severe TBI group recalled least words and the mild TBI group most words, with all groups showing some improvement from acute to 24 month assessments. For the delay trial there was a significant effect of Severity (F(2,60)=9.7, p<.001), and a Severity x Time interaction effect (F(3,180)=2.4, p<.05). The results revealed a similar pattern to those described above, with all TBI groups improving from the acute stage to 24 months post-injury, with most change evident between acute and to 12 months post-injury, suggesting a practice effect on this task.
As in the verbal task, the results for the Visual Learning Test indicated a significant main effect of Severity ($F(2,64)=4.2$, $p<.05$) and Time ($F(6,192)=6.2$, $p<.001$) for the overall standard score. The severe TBI group performed the poorest and the mild TBI group the best, and again all groups improved over time. The delay trial showed a similar pattern, with a significant main effect of Severity ($F(2,60)=4.3$, $p<.05$). However, when looking at the results closely, the severe TBI group appeared to show the most fluctuation in results, with the 12 months post-injury score poorer than at the acute and 6 monthly stages post-injury.
Table 9.3: Multi-trial learning results

<table>
<thead>
<tr>
<th>Multi-trial learning</th>
<th>Mild TBI</th>
<th>Moderate TBI</th>
<th>Severe TBI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WRAML-standard score</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute M (SE)</td>
<td>9.9 (0.5)</td>
<td>9.1 (0.5)</td>
<td>7.1 (0.7)</td>
</tr>
<tr>
<td>6 months M (SE)</td>
<td>11.6 (0.5)</td>
<td>10.9 (0.5)</td>
<td>8.9 (0.7)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>13.5 (0.5)</td>
<td>11.7 (0.5)</td>
<td>10.9 (0.7)</td>
</tr>
<tr>
<td>24 months M (SE)</td>
<td>13.4 (0.5)</td>
<td>11.4 (0.5)</td>
<td>10.3 (0.7)</td>
</tr>
<tr>
<td><strong>WRAML-Delayed Trial</strong></td>
<td>*** a b c d e f</td>
<td></td>
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</tr>
<tr>
<td>Acute M (SE)</td>
<td>7.7 (0.5)</td>
<td>6.8 (0.4)</td>
<td>4.51 (0.7)</td>
</tr>
<tr>
<td>6 months M (SE)</td>
<td>8.3 (0.5)</td>
<td>8.7 (0.5)</td>
<td>6.6 (0.8)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>10.2 (0.5)</td>
<td>9.0 (0.4)</td>
<td>6.7 (0.7)</td>
</tr>
<tr>
<td>24 months M (SE)</td>
<td>11.3 (0.4)</td>
<td>9.8 (0.5)</td>
<td>7.7 (0.7)</td>
</tr>
<tr>
<td><strong>Visual learning:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>WRAML-standard score</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute M (SE)</td>
<td>11.5 (0.6)</td>
<td>10.3 (0.5)</td>
<td>8.4 (0.8)</td>
</tr>
<tr>
<td>6 months M (SE)</td>
<td>11.8 (0.6)</td>
<td>11.2 (0.5)</td>
<td>9.4 (0.7)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
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<td>11.8 (0.6)</td>
<td>9.5 (0.8)</td>
</tr>
<tr>
<td>24 months M (SE)</td>
<td>12.3 (0.6)</td>
<td>11.2 (0.5)</td>
<td>10.4 (0.8)</td>
</tr>
<tr>
<td><strong>WRAML-Delayed Trial</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Acute M (SE)</td>
<td>8.9 (0.6)</td>
<td>8.3 (0.6)</td>
<td>6.0 (0.9)</td>
</tr>
<tr>
<td>6 months M (SE)</td>
<td>9.6 (0.6)</td>
<td>9.4 (0.6)</td>
<td>7.0 (0.9)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>9.7 (0.6)</td>
<td>9.2 (0.6)</td>
<td>5.9 (0.9)</td>
</tr>
<tr>
<td>24 months M (SE)</td>
<td>9.2 (0.7)</td>
<td>8.9 (0.6)</td>
<td>7.6 (1.0)</td>
</tr>
</tbody>
</table>

Main effect of Group: * p<.05; **p<.01; ***p<.001; Main effect of Time: ^^ p<.001; 
^Group x Time interaction p<.05; ^significant difference between mild and severe TBI groups at T4; ^significant difference between mild and severe TBI groups at T1;
significant difference between mild and severe TBI groups at T2; 6significant difference between mild and severe TBI groups at T3; 7significant difference between mild and moderate TBI groups at T4; 8significant difference between moderate and severe TBI groups at T1; 9significant difference between moderate and severe TBI groups at T3; 10significant difference between moderate and severe TBI groups at T4. 11significant difference between moderate and severe TBI groups at T2

Trials 1-4 of the Verbal Learning test were also compared. Results generally indicated a significant effect of Severity within each time point (acute, 6, 12 and 24 months post-injury): \( (E(2,62)=7.1, p<.01), (E(2,64)=7.1, p<.01), (E(2,64)=6.8, p<.01), (E(2,63)=9.9, p<.001) \). These results again indicated clearly that the mild TBI group performs most efficiently, that all TBI groups showed improvement over time, and that all groups recalled more words on the Trial 4 compared to the first Trial 1 (See Figures 9.1-9.4).

![Graph showing the number of words recalled across different trials for Mild TBI, Moderate TBI, and Severe TBI groups.]

Figure 9.1: Verbal Learning Test trials 1-4 at the acute (0-3) months stage
Figure 9.2: Verbal Learning Test trials 1-4 at the 6 monthly stage.

Figure 9.3: Verbal Learning Test trials 1-4 at the 12 monthly stage.
Analysis also revealed a significant main effect of Severity, when comparing visual learning trials 1-4, within each time point at the acute, 6 and 12 month post-injury stages: (F(2,62)=5.1, p<.01); (F(2,64)=5.8, p<.01); (F(2,64)=4.2, p<.05). As in the Verbal Learning Test, the mild TBI group performed the best (similar to the moderate TBI group), with the severe TBI group performing distinctly below the other TBI groups. (see Figure 9.5-9.8).
Figure 9.6: Visual Learning Test trials 1-4 at the acute 6 monthly stage

Figure 9.7: Visual Learning Test trials 1-4 at the acute 12 monthly stage
Predictors of memory measures:

In an attempt to find possible predictors for memory outcome, stepwise multiple regressions were undertaken utilising the following variables – VABS (pre-injury), severity, Injury age, and SES (see Table 9.2). For simple non-standardised tests in the area of immediate memory, it was not surprising that age at injury, proved to be the best, though not strong, predictor, explaining approximately 5% of the variance. With regard to tasks of short-term memory/encoding, though again non-standardized measures, severity and injury age both contributed to the prediction of outcome (10-16% of the variance). The multi-trial verbal learning task, a standardised measures, was best predicted by severity and VABS (pre-injury), with these variables explaining 32% of the variance. Similarly, the multi-trial visual learning task was also best predicted (18% of the variance) by severity and VABS (pre-injury).
Table 9.4: Predictors of memory ability two years post-TBI

<table>
<thead>
<tr>
<th>Outcome measure</th>
<th>Predictor</th>
<th>r</th>
<th>r²</th>
<th>F</th>
<th>p</th>
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<tr>
<td>Immediate memory:</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>DF</td>
<td>Injury age</td>
<td>0.22</td>
<td>0.05</td>
<td>3.03</td>
<td>0.09</td>
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<tr>
<td>BS</td>
<td>Injury age</td>
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<td>0.06</td>
<td>3.78</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>Severity</td>
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<td>0.11</td>
<td>3.15</td>
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<tr>
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<td>VABS</td>
<td>0.39</td>
<td>0.15</td>
<td>2.74</td>
<td>0.10</td>
</tr>
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<td>Short-term memory/encoding:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSS</td>
<td>Severity</td>
<td>0.31</td>
<td>0.10</td>
<td>6.31</td>
<td>0.02</td>
</tr>
<tr>
<td>CFR-recall</td>
<td>Injury age</td>
<td>0.33</td>
<td>0.11</td>
<td>7.29</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Severity</td>
<td>0.40</td>
<td>0.16</td>
<td>3.48</td>
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<td></td>
<td></td>
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<td>Verbal-Learning Test</td>
<td>Severity</td>
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<td>18.82</td>
<td>0.00</td>
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<td></td>
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<td>0.36</td>
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<tr>
<td>Visual Learning Test</td>
<td>VABS</td>
<td>0.31</td>
<td>0.10</td>
<td>6.24</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Severity</td>
<td>0.42</td>
<td>0.18</td>
<td>5.82</td>
<td>0.02</td>
</tr>
</tbody>
</table>

9.4: Discussion

The results of the present study provide support for the presence of memory difficulties in the acute, 6, and 12 and 24 months stages post-TBI. As previously noted in Chapter 6 all TBI groups were functioning similarly pre-injury, with no age, gender or socioeconomic differences identified. Therefore post-injury differences may be interpreted with reference to injury-related factors. In general, the findings from the study indicate a strong dose-response relationship between injury severity and aspects of memory function. Recovery post-TBI was evident, although children with severe TBI maintained residual memory impairment even 24 months post-injury. Finally, the pattern of memory impairment documented in the study suggests specific deficits for complex memory processes, with more simple, automatic memory skills relatively intact.
While results on the verbal memory tasks demonstrated a dose-response relationship, however, this pattern varied depending on the task demands. Results indicated that all TBI groups performed similarly on simple immediate memory tasks regardless of modality. For immediate auditory recall, all groups showed slight improvement during the 24 months post-injury. The nature of the task tapping these skills suggests that this improvement was unlikely to be due to practice affects, since the task required the encoding and repetition of a series of digits. Rather, improvements may reflect normal age developmental gains over the 24 month study period. Such clear increments were not observed for immediate visual recall, with more fluctuations evident, consistent with findings from the developmental literature showing early maturation of basic visual memory skills (Anderson & Lajoie, 1996).

For tasks of short-term memory, which require some encoding and storage of information, some modality/task differences were identified. First, all groups demonstrated improvement over time on these measures. Unlike the immediate memory tasks, this observed improvement may be due, at least in part, to practice effects, with some children remembering the stimulus material from one assessment time to the next. Evidence for such practice effects across all groups indicates a capacity for all TBI groups to utilize context and meaning as a strategy to assist in the recall of lengthy verbal information, regardless of injury severity. Second, for the verbal memory task, story recall, the moderate and severe TBI groups seem to plateau by 12 months post-injury, scoring a little poorer at 24 months post-injury compared to 12 months post-injury. These results suggest that while children who sustained a mild TBI continue to benefit from exposure to a task, the moderate and severe TBI groups appear to reach a limit and then plateau, perhaps benefiting less from memory strategies, supporting the significant difference observed on this task, between the mild and severe TBI groups at 24 months post-injury. With regard to the short-term visual memory task, again a dose-response relationship was evident, however, the mild and severe TBI groups were most discrepant at the acute and 6 month follow-up, with performance becoming more similar at 12 and 24 months post-injury, perhaps reflecting practice effect/recovery/strategy utilisation, by all
TBI groups, in order to maintain adequate performance on this task. These results may relate to the maturity of visual memory abilities, with insult having limited capacity to permanently disrupt these established skills, or perhaps to the nature of the task, with the visual task having low demands in terms of processing speed and efficiency.

For multi-trial memory and learning tasks, the child has the opportunity to increase retention over time, and to develop and implement strategies to aid recall. On these tasks, yet again, the severe TBI group performed most poorly, achieving a significantly lower overall recall in comparison to the other groups. All TBI groups displayed the expected improvement across trials on these tasks, and all showed improvement from acute to 24 month evaluations, suggesting that the repeated exposure to the information over the trials and practice effects (over time) contributed to these scores.

The lack of efficiency of the severe TBI group for measures of short-term memory and learning, in the context of intact immediate capacity is worthy of consideration. These poorer performances may be due to greater temporal lobe pathology, causing poorer encoding and consolidation of new material. However, the contribution of other cerebral areas may also be significant. For example, the observation of intact performance on more simple, automatic tasks, in contrast to significant severity effects for complex learning activities suggests less efficient allocation of attention and poorer generation and/or implementation of strategies for severely injured children. Such an interpretation is consistent with that of Harris (1996) where it was reported that children with severe TBI used an inefficient passive rehearsal strategy, were restricted to simple rehearsal strategies, were less able to modify their strategies and had limited awareness of their memory skills. Furthermore, the differential deficiencies identified for verbal memory, may reflect the reliance of these skills on factors such as intact processing speed, which are reduced in the early stages post-TBI. Alternatively, verbal difficulties (plateau reached by 12 months post-injury) may be associated with the developmental level of these skills, with verbal skills still emerging and developing in our sample, in
contrast to visual memory skills which are more fully established by middle childhood and so may be more resilient post-injury (Anderson & Lajoie, 1996; Pressley and Schneider, 1997).

Interpretation of results from this study suggests that while some recovery was evident on most tasks where initial difficulties were identified, significant residual impairments were documented for children with severe TBI. Further follow-up into adolescence and young adulthood is necessary to determine the full extent of these problems.

Regression analysis provided possible predictors in the memory area. With regard to the more simple immediate memory tasks, injury age was the best predictor. Considering that these tasks are both non-standardised and simple, it was not surprising that an age factor is important in the successful completion. With regard to short-term/encoding memory tasks, both severity and injury age were the better predictors. Again these are non-standardised measures and so an age effect is expected, but of interest was the emergence of the severity factor, suggesting that as task complexity/demand increases, then a child’s level of injury also has an impact on performance. When considering the complex multi-trial task, performance was again influenced by level of injury, as well as pre-morbid functioning, suggesting that a higher level of cognitive skill is incorporated when completing these more complex memory tasks.

Conclusions

In conclusion, the present study suggests that memory difficulties do occur in the acute stage and up to 24 months following childhood TBI. Children who had sustained a severe TBI generally performed more poorly over the 24 months post-TBI than those children who had sustained mild or moderate injuries, with results indicating a dose-response relationship for severity and memory impairment.

In the present study TBI children presented with intact immediate memory capacity and more difficulty on complex tasks (regardless of modality) requiring the
use of encoding, rehearsal and organisational strategies. While ongoing recovery was evident for the severe TBI group, they continued to perform at lower than expected levels. It may be suggested that unlike simple tasks, more complex tasks depend on the integrity of a number of cerebral regions which may have been impacted by injury, therefore leading to more difficulties for those who sustained a more significant injury, on the more demanding tasks. However, a limitation of the current study is the exclusion of a memory recognition task, making it difficult to distinguish between spontaneous recall difficulties, especially on the more complex tasks, compared to retrieval impairments, a factor that is important to investigate in future research. Storing, consolidating and retrieving information is essential for normal developmental progress, and so it is essential that these skills are monitored closely following all TBI. With a clearer understanding of the memory deficits following TBI, appropriate strategies can be taught and interventions implemented for these children.
Chapter 10

Recovery of educational skills following paediatric traumatic brain injury: Functional outcomes.

10.1: Introduction:

The demand of academic activities requires that each student is able to deal with cognitive, communicative, visual-spatial, physical and psychosocial challenges. Of most importance, success in the classroom setting requires the student to integrate, remember and retrieve large amounts of information, and to be able to use attentional capacity efficiently (Milton, Scaglione, Flanagan, Cox, & Rudnick, 1991). Therefore, it is not surprising that following a closed head injury, where attention, memory and learning capacities are often affected, that children’s skills in the areas of reading, spelling and arithmetic, will be compromised.

A number of studies have reported information on school placement as an indicator of educational performance following TBI (Kinsella et al., 1995; Kinsella et al., 1997). It was found that at one year post-injury, children with moderate to severe TBI were more likely to require special assistance at school. At two years post-injury, while all children had returned to school, seven out of ten children with severe injuries received special education, two out of five of the moderate group, and none of the mild group. Similar results were also reported (Stalings, Ewing-Cobbs, Francis, & Fletcher, 1996), where children with more severe injuries presented with greater educational difficulties in the first two years post-TBI. These findings suggest that specialist assistance is directly related to injury severity.

Studies have also measured educational performance in terms of reading, spelling and arithmetic skills, rather than school placement. The impact of head injury on later reading skills in a group of school aged children, aged between 7 and 12 years was investigated (Schaffer, Biju, Chadwick, & Rutter, 1980). These children had sustained a compound depressed fracture of the skull, causing damage to the underlying brain. It was found that one third of the children had a reading age at least 24 months behind their chronological age. Severe reading
backwardness was significantly associated with a history of post-traumatic cerebral oedema. It was suggested that the effect of a head injury on reading ability is mediated through a lowering of general intelligence.

Similarly, it was reported that both initially, and at six months post-injury, a sample of children who had sustained a closed head injury was functioning lower academically (spelling, mathematics, reading and word recognition) and intellectually, in comparison to their peers. Furthermore, the performance of 15 children who sustained a closed head injury with a mean coma of nine days was investigated. These children were seen 3-6 months and then one year post-injury. It was found that arithmetic was poorer than either reading or spelling. Difficulties were found to persist after the children’s IQ level had improved (Berger-Gross & Schackelford, 1985; Slater & Kohr, 1989).

A more in depth investigation of reading skills following childhood head injury was undertaken (Barnes, Denis, & Wilkinson, 1999). These authors hypothesised that if head injury affects the acquisition of skills not yet acquired, then younger children (before formal reading instruction), should be at the highest risk for difficulties in acquiring the basics of reading, such as word decoding. For children injured in middle childhood, where comprehension skills (e.g. inferencing) are still being acquired, the risk may be greatest for reading comprehension, where decoding accuracy and decoding speed may be compromised. In keeping with their predictions, results showed that children who sustained injuries during pre-school years or in early primary grades, as well as children with left-sided or bilateral contusions, were most at risk for difficulties in both decoding and comprehension skills. Children between the ages of 6.5 and 9 years at the time of injury, performed better than younger children, but more poorly than an older group of children, again suggesting some compromise in skills for injuries sustained during this age range. It was also found that reading fluency was related to reading comprehension, suggesting that slow word-level processing has negative consequences for reading comprehension.
Another functional area where there is limited literature, is the area of adaptive functioning. It has been reported that post-TBI, children display more problem behaviours, are less socially competent and show less adaptive living skills compared to sibling controls (Asarnow, Satz, Light, Lewis, & Neumann, 1991; Greenspan & MacKenzie, 1994; Papero, Prigatano, Snyder, & Johnson, 1993; Perrott, Taylor, & Montes, 1991). Furthermore, Fletcher, Ewing-Cobbs, Miner, Levin, and Eisenberg (1990) found that children who sustained severe head injuries displayed a decline in adaptive functioning, had more school problems and engaged in less social activities, whereas those with mild-moderate injuries did not deviate from average levels of functioning. However, absent from this literature is information regarding the recovery or further development of these skills following traumatic brain injury.

While past research has identified educational and adaptive difficulties following moderate to severe TBI in childhood, there is less known about the pattern of recovery of these skills, with the majority of studies assessing skills at one time point, or for a short period post-injury. The aim of the present study was to map the recovery of educational and adaptive skills over twenty-four months post-TBI. Based on past literature, it was hypothesized that: (i) a dose-response relationship exists between injury severity and educational and adaptive skills, with more severe TBI associated with greater impairment; (ii) arithmetic skills which continue to develop rapidly through childhood, will be more compromised than reading and spelling skills, which are consolidated in early primary years.

10.2: Method:
10.2.1: Participants

The sample comprised 69 children who had sustained a documented TBI, and represented consecutive admissions to the neurosurgery ward of the Royal Children's Hospital, Melbourne, between June 1994 and August 1997. Of these children, 51 were male and 18 were female (7 children were excluded from the original sample due to missing data).
### 10.2.2: Measures

**Teacher questionnaire:**

*Rowe Behavioural Rating Inventory - Teacher version* (RBRI: Rowe & Rowe, 1995): Refer to Chapter 8 for a description of this questionnaire. An extension to the Inventory was also included (Rowe-Educational: Rowe-E), where teachers were also asked to rate the child’s pre-injury ability in the areas of reading accuracy, reading comprehension, spelling and arithmetic. A five point rating scale was used where a rating of 1 indicated ‘far below grade level’ and a score of 5 indicated ‘far above grade level’.

**Parent questionnaire:**


**Educational measures:**

(a) *The Wide Range Achievement Test - 3.* (WRAT-3: Wilkinson, 1993): assessed reading, spelling and arithmetic skills. The child is first required to read a list of unrelated words. The examiner then reads a list of words which the child writes down, and thirdly written arithmetic is presented and the child is instructed to complete as many mathematical equations as possible, with a maximum time limit of 15 minutes. The WRAT-3 has alternate forms and these were utilized in order to minimize any practice effect. The WRAT-3 is a standardized test with a mean of 100 and a standard deviation of 15.

(b) *Wechsler Individual Achievement Test* (WIAT: Wechsler, 1992): assessed listening comprehension. The examiner read aloud a series of short stories, and after each story the child was asked related comprehension questions. The WIAT is also a standardised test with a mean of 100 and a standard deviation of 15.

### 10.2.3: Procedure

Educational tests were administered by a qualified psychologist during the acute, 12 and 24 months post-injury.
10.2.4: Statistical analysis

The three groups (mild, moderate, severe TBI) were initially compared on injury and demographic characteristics and on pre-injury measures of ability (VABS) and educational skills (Rowe-E) to identify any differences across the groups that could influence post-injury performance. One-way analysis of variance (ANOVA) and Chi-Square were conducted to compare pre-injury, intellectual, and specific medical variables. Repeated measures analysis of covariance (Group x Time, covarying for pre-injury ability) examined the association between injury severity and performance across the time points. Tukey’s HSD statistic was utilised to ascertain specific group differences. For both the educational measures, one severe TBI child’s scores were windsorized, and the child was assigned a score of two standard deviations below the total group mean.

10.3: Results:

Comparison of pre-injury ability

The Rowe-E was examined (see Table 10.1) and analysis indicated no group differences. Chi-square and ANOVA indicated no significant differences between the groups with regard to pre-injury abilities in the areas of reading accuracy, reading comprehension, spelling, arithmetic, and the areas of Attention ($F(2,68)=1.08$, ns) and Restlesness ($F(2,68)=1.4$, ns) as measured by the RBRI and ROWE-E. These results suggest that any difference between the groups post-injury could not be fully explained by pre-injury status.
Table 10.1: Pre-injury information for the sample

<table>
<thead>
<tr>
<th>Pre-injury results:</th>
<th>Mild TBI</th>
<th>Moderate TBI</th>
<th>Severe TBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rowe-E: Reading accuracy (n,%)</td>
<td>7 (29)</td>
<td>11 (39)</td>
<td>2 (13)</td>
</tr>
<tr>
<td>Rowe-E: Reading comp. (n, %)</td>
<td>5 (21)</td>
<td>11 (39)</td>
<td>2 (13)</td>
</tr>
<tr>
<td>Rowe-E: Spelling (n,%)^</td>
<td>5 (21)</td>
<td>14 (50)</td>
<td>3 (20)</td>
</tr>
<tr>
<td>Rowe-E: Arithmetic (n,%)^</td>
<td>2 (8)</td>
<td>6 (21)</td>
<td>- (0)</td>
</tr>
<tr>
<td>RBRI: Attention Domain M (SD)</td>
<td>10.9 (4.5)</td>
<td>12.3 (4.7)</td>
<td>10.4 (4.4)</td>
</tr>
<tr>
<td>RBRI: Restlessness Domain M (SD)</td>
<td>8.6 (2.9)</td>
<td>7.6 (3.4)</td>
<td>7.2 (2.8)</td>
</tr>
</tbody>
</table>

^ number and percentage below Grade level

**Adaptive performance**

For the Communication Domain, there were significant main effects of Group ($F(2,54)=3.4, p<.05$) and Time ($F(3,162)=7.6, p<.001$). Post hoc analysis revealed a significant difference between the mild TBI and moderate TBI groups at 6 months post-injury. Generally, all the TBI groups performed more poorly over time, with the severe TBI group showing the biggest decrement. With regard to the Daily Living Skills Domain, results were not statistically significant, however, visual inspection of the data suggests that, unlike the mild and moderate TBI groups, the severe TBI group showed a decline from the acute to 24 months post-injury. ANOVA revealed significant main effects of Group ($F(2,51)=3.3, p<.05$), Time ($F(3,153)=5.6, p<.01$) and an interaction effect ($F(3,153)=3.6, p<.01$). Again, unlike the mild and moderate TBI groups, results indicate that the severe TBI group struggle in the social skills area by 24 months post injury. The Total Adaptive score revealed a significant main effect of Time ($F(3,150)=4.8, p<.01$), where all TBI groups, to some degree, performed more poorly over time, the largest decrement by the severe TBI group (see Table 10.2).
Table 10.2: Adaptive functioning skills

<table>
<thead>
<tr>
<th></th>
<th>Mild TBI</th>
<th>Moderate TBI</th>
<th>Severe TBI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Communication Domain</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute M (SE)</td>
<td>108.8 (2.7)</td>
<td>103.6 (2.4)</td>
<td>104.0 (4.4)</td>
</tr>
<tr>
<td>6 months M (SE)</td>
<td>107.8 (3.4)</td>
<td>96.6 (3.1)</td>
<td>89.1 (5.7)</td>
</tr>
<tr>
<td>12 months M (SE)</td>
<td>105.2 (2.8)</td>
<td>99.2 (2.5)</td>
<td>97.4 (4.6)</td>
</tr>
<tr>
<td>24 months M (SE)</td>
<td>103.5 (3.4)</td>
<td>96.9 (3.0)</td>
<td>90.4 (5.6)</td>
</tr>
</tbody>
</table>

| **Daily Living Skills Domain** |            |              |            |
| Acute M (SE)             | 99.0 (2.8) | 99.0 (2.6)   | 98.7 (4.9)|
| 6 months M (SE)          | 104.1 (3.3)| 97.4 (3.1)   | 91.0 (5.9)|
| 12 months M (SE)         | 100.5 (2.7)| 101.2 (2.5)  | 90.9 (4.7)|
| 24 months M (SE)         | 98.9 (2.9) | 96.6 (2.7)   | 87.0 (5.1)|

| **Social Skills Domain**  |            |              |            |
| Acute M (SE)             | 102.4 (3.1)| 102.2 (2.9)  | 102.4 (5.1)|
| 6 months M (SE)          | 105.0 (3.5)| 95.1 (3.2)   | 88.9 (5.6)|
| 12 months M (SE)         | 105.0 (3.2)| 101.8 (2.9)  | 88.4 (5.2)|
| 24 months M (SE)         | 103.7 (3.1)| 97.1 (2.8)   | 83.5 (5.0)|

| **Total Score: Adaptive Functioning** |            |              |            |
| Acute M (SE)              | 104.5 (3.2)| 101.5 (3.0)  | 102.1 (5.6)|
| 6 months M (SE)           | 107.3 (3.8)| 96.0 (3.5)   | 88.4 (6.7)|
| 12 months M (SE)          | 104.7 (3.2)| 101.1 (2.9)  | 89.3 (5.5)|
| 24 months M (SE)          | 102.8 (4.3)| 92.0 (4.0)   | 84.7 (7.5)|

Main effect of Group: *p<.05; Main effect of Time: *p<.01; ^^p<.001; Group x Time interaction p<.01; "significant difference between mild and moderate TBI groups at T2; "significant difference between mild and severe TBI groups at T2; "significant difference between mild and severe TBI at T3; "significant difference between mild and severe TBI groups at T3.
Educational performance

(i) Reading accuracy:

Results for all educational measures are seen in Figures 10.1-10.4. For reading accuracy, repeated measures ANCOVA revealed a significant main effect of Group ($F(2,63)=3.6, p<.05$). Post hoc analysis revealed a significant difference between the mild TBI and moderate TBI groups at 12 and 24 months post-injury. As expected, the mild TBI group achieved the highest scores, however, unexpectedly, the moderate and severe TBI groups performed similarly across all time points.

![Graph showing mean reading scores over time for Mild TBI, Mod TBI, and Severe TBI groups.]

Figure 10.1: Reading accuracy results at 0-3, 12, & 24 months post-TBI.

(ii) Spelling:

When investigating spelling skills, there were no significant main effects for Group ($F(2,63)=2.3, ns$) or Time ($F(2,126)=0.2, ns$), however, a non-significant trend showed that the moderate TBI group achieved the lowest score and the mild TBI group the best score, however all scores remained relatively stable from acute to 24 months post-injury. As in the reading component, the moderate TBI group performed more closely to the severe TBI group than the mild TBI group.
(iii) Arithmetic:

Repeated Measures ANCOVA revealed a significant main effect of Group ($F(2,63)=15.1$, $p<.001$), where a clear dose response relationship was evident. The severe TBI group presented with most difficulty in this area compared to the mild and moderate TBI groups. Of interest, the severe TBI group generally performed below the "Average" range, and did not show much change/recovery from the acute to 24 months post-injury.
(iv) **Listening comprehension:**

With regard to the listening comprehension task, ANOVA revealed a significant difference between the TBI groups ($F(2,63)=4.8$, $p<.05$), where again a dose-response relationship was clear. It is worthy of note that even though the moderate and severe TBI groups performed similarly in the reading and spelling areas, the severe TBI group struggled more-so when asked to process verbal information, extract meaning, and answer comprehension questions.

![Chart showing mean comprehension scores for mild, moderate, and severe TBI groups.]

Figure 10.4: Listening Comprehension results at 0-3, 12, & 24 months

**10.4: Discussion:**

The results of the present study provide support for the presence of educational and adaptive difficulties following moderate to severe traumatic brain injury. Importantly, results from the Vineland Adaptive Behavior Scale indicate that the TBI groups were functioning similarly pre-injury. However, although not significant, a larger percentage of the moderate TBI group were having difficulty on the pre-injury educational measures. These findings suggest that any post-injury differences may be interpreted with reference to a combination of pre-injury and injury-related factors.
Adaptive functioning skills:

When investigating the adaptive functioning results, findings generally indicate a dose-response relationship, where the mild TBI group performs more strongly than the moderate and severe TBI groups, and where the largest decrement between acute and 24 months results is evident for the severe TBI group. Of most interest are the results for the Communication and Social Skills Domains where the severe TBI group show a decrement of 14 and 19 points respectively. Since the ability to communicate effectively and acquire a repertoire of social skills is to some degree dependant on attentional and memory skills (e.g. for turn-taking in conversation, for attending to and keeping the flow of a conversation in mind), it is not surprising that the severe TBI group present with these difficulties. Furthermore, as adolescence approaches, demands are often more complex, resulting in cumulative deficits over time. These results suggest an important area for rehabilitation in the acute stage following an injury, and during transition periods (e.g.: moving from primary to secondary school.

Reading accuracy and spelling:

With regard to reading and spelling skills, the results did not demonstrate a clear dose-response relationship. While the mild TBI group achieved the highest scores, the moderate and severe TBI groups performed similarly, at all time points. These results do not support Schaffer et al. (1980), where one third of the sample was reading at least 24 months behind their chronological age, with the suggestion that the effect of head injury on reading ability is mediated through a lowering of general intelligence. The current results have revealed that, while the moderate TBI group has performed better on the standardized test of intellectual ability, in comparison to the severe TBI group, the two TBI groups are performing similarly on these educational measures.

A possible explanation involves the pre-injury level of these skills. While statistical analysis revealed no significant pre-injury difference between the TBI groups in these skill areas, there was a trend for a higher percentage of the moderate TBI group to be performing below Grade level. Comparing analyses with and
without covarying for pre-injury educational ability, it is clear that a child’s pre-
morbid skill level in the reading and spelling areas affects their ability 2 years post
TBI. Furthermore, regression analysis indicated pre-injury reading accuracy and
spelling ability were significant predictors of performance in these areas two years
post injury. These results also support Kinsella et al. (1997) and Berger-Gross and
Schackelford (1985), where it was suggested that reading skills tend to be resilient
following TBI. Another possible explanation has been put forth by Barnes et al.
(1999), where it was stated that head injury affects the acquisition of skills yet to be
acquired. Since the current sample acquired their injuries between the ages of 8-12,
it may be suggested that reading and spelling had already been established, and so
were less vulnerable to the effects of a traumatic brain injury.

Listening Comprehension:

Results indicated a dose response relationship for listening comprehension, with
a significant difference between the mild and severe TBI groups. However, while
the mild TBI group performed within the upper end of the “Average” range, the
severe TBI group, also performed within the “Average” range, however at the lower
end, suggesting mild difficulty in this area. These results support Barnes et al.
(1999), where it was stated that for children injured in middle childhood, the risk
may be greatest for comprehension skills, as these skills (e.g. inferencing) are still
being acquired at the time of the injury, and so an interruption affects the normal
development of these skills. A further explanation may be related to memory
function, with the argument being that the severe TBI group do not recall the story
as well as the other TBI groups, and so have difficulty with the comprehension of
the material. However, this seems unlikely since most of the stories were not
lengthy, and the children were provided with structured questions relating to each
story, a cue that assists the recall of the material. Furthermore, a recent paper
(Catroppa & Anderson, in submission) found that the three TBI groups did not
differ significantly with regard to immediate and short-term auditory memory, with
differences apparent on more complex multi-trial memory and learning tasks.
Arithmetic:

Arithmetic scores were significantly different between the TBI groups, with results again demonstrating a dose response relationship. While the mild and moderate TBI groups generally performed within the “Average” range at all time points, the severe TBI group performed within the “Borderline” to “Low Average” range. These results support Berger-Gross and Schackelford (1985), where it was found that, post-injury, arithmetic was poorer than either reading or spelling. Arithmetic requires the integration of a number of skills, including attention, memory, sequencing, organisational ability and problem-solving, and this may render the severe TBI groups as most vulnerable.

Conclusions

In conclusion, the present study suggests that educational and adaptive difficulties are present up to twenty-four months following moderate-severe traumatic brain injury. While a dose response relationship was evident for listening comprehension and arithmetic, this relationship was not so clear with regard to reading accuracy and spelling, where children with a moderate or severe injury achieved similar results, suggesting factors other than severity of injury influence the level and recovery of these skills over time. It is important to document predictors of outcome in the educational and adaptive areas, and this will be investigated in the following chapter.

These results from the present study are informative and clear, with areas such as recovery of educational skills investigated, resulting in findings not investigated or reported in previous research. These results stress the need for follow-up of children post-TBI, so that preventative measures in the adaptive and educational areas can be provided in the school setting, and children at risk can be identified before difficulties are further exacerbated.
Chapter 11: Predictors of educational and adaptive outcome

11.1 Introduction:

There have been a number of studies documenting outcomes following paediatric TBI. Many of these studies have indicated poorer performance for TBI children in areas including intellectual ability (Chadwick et al., 1991; Dikeman et al., 1990; Ewing-Cobbs et al., 1997; Gulbrandson, 1993; Jaffe et al., 1992, 1993, 1995; Tremont, Mittenberg, & Miller, 1999; Wrightson et al., 1995), memory skills (Anderson et al., 1997; Donders, 1993; Harris, 1996; Levin & Eisenberg, 1979; Levin et al., 1982; Levin et al., 1988; Yeates et al., 1995), educational ability (Barnes et al., 1999; Berger-Gross & Schackelford, 1985, Kinsella et al., 1995, 1997; Schaffler et al., 1980), and a paucity of studies investigating attentional outcomes (Anderson & Pentland, 1998; Dennis et al., 1995; Kaufman et al., 1993; Timmermans & Christensen, 1991).

While these outcome studies give an indication of outcomes in a variety of cognitive areas, using a cross-sectional or longitudinal design, there remains much question as to the predictors of outcome following childhood brain trauma. This is a complex area as different predictors will be significant depending on the outcome measures, the stage of the recovery process, and the research question being investigated.

Despite the complexity of this issue, a number of researchers have identified predictors of outcome in the TBI area. Depth and duration of coma, as measured by the GCS (refer to Chapter 2) has been found to be a significant predictor of outcome (Goldstein & Levin, 1992; Levin et al., 1988), where a low GCS appears indicative of poor cognitive outcome, and a higher GCS score more predictive of minimal or no cognitive deficits. A longer period of impaired consciousness has also been linked to impairments in intellectual ability. A similar relationship has been reported between increasing duration of PTA and cognitive, neurological and behavioural impairments (Gronwall & Wrightson, 1981, Rutter et al., 1981).
Furthermore, researchers (Levin et al., 1988; Miller, 1981) have reported memory and intellectual deficits in patients with non-reactive pupils. Other predictors that have been reported, which are also used to establish the severity of injury, are radiological measures such as CT, PET and MRI, where correlations have been reported between radiological measures and neuropsychological assessment and school problems (Levin et al., 1993; Stein & Spettel, 1995).

Some controversy exists in the literature with regard to pre-injury levels of functioning (Haas, Cope, & Hall, 1987) and their relationship to outcomes following childhood TBI. Some authors suggest that children who sustain a severe TBI present with a higher pre-injury incidence of character disturbance than the normal population, therefore suggesting that post-injury difficulties may just be a reflection of pre-injury characteristics (Cattelani, Lombardi, Brianti, & Mazzuchi, 1998). In contrast, others have reported that a minority of children who sustained head trauma appeared to have pre-morbid disturbances, and so did not feel that pre-injury characteristics contributed to the sequelae often witnessed following head-injury (Donders, 1992).

Other predictors of outcome following head trauma, that might be described as ‘developmental’ predictors are age at injury and time since injury. Again, controversy exists with regard to age at injury with some researchers indicating that children injured at a younger age show similar deficits to those injured at an older age (Klonoff, Low, & Clarke, 1977; Vignolo, 1980), and others reporting that younger age at injury is associated with an increased vulnerability of emerging skills, and so will lead to poorer outcome when compared to children whose injuries were sustained later in childhood (Anderson & Moore, 1995, Anderson et al., 1997; Kriel, Kratch & Panse, 1989; Thompson et al., 1994). The amount of time that has lapsed since the injury is also considered a predictor of outcome. Improvement of all functions is generally reported in the first year (Chadwick et al., 1981; Klonoff et al., 1977), however some findings suggest that not all deficits may be seen soon after the injury, but may present at a later time when a specific skill, appropriate for a given age, has not developed appropriately (Wrightson, McGinn, & Gronwall,
1995). Therefore, incorporating a developmental framework is important when measuring outcome in different cognitive domains, where skills are developing at diverse rates through-out childhood.

Another area, more external to the TBI child, is the level of family functioning, that is, the environment provided for the child during the recovery process. A few studies have examined pre-injury family characteristics that may affect both the functioning of the family and child post-injury. In general, conclusions suggested that strong pre-injury functioning, a high level of cohesiveness, a low level of control and positive family relationships were predictive of good behavioural, cognitive and educational outcomes post-injury (Anderson et al., in submission; Max et al., 1998; Rivara et al., 1995, Taylor et al., 1999; Yeates et al., 1997).

In light of the previous research outlined above, the aim of this chapter is to investigate a broad range of possible predictors of outcome two years post-injury in the educational (reading, spelling, arithmetic, and comprehension) and adaptive functioning areas, reflecting the possible contribution of injury and intellectual factors, previously noted, as well as developmental and psycho-social factors. At the outset of this thesis, a simple model of information processing was presented, where attentional variables were presented as a first step in the prediction of educational and adaptive outcomes. When taking into account the results in Chapters 7-10 of this manuscript, the model presented in Chapter 6 is still relevant, but at this stage, has become more complex. Therefore, as stated above, the aim of this chapter is to investigate predictors of educational and adaptive outcome, using a more complex model of information processing (see below and Figure 11.1). The model suggests that pre-injury, injury/developmental and psycho-social variables may all be possible predictors of attention, and all these variables may in turn, be predictive of functional outcome.
Figure 11.1 Predictors of educational and adaptive outcomes.
11.2: Method:

11.2.1: Measures

The following measures were employed in statistical analyses to determine the pattern of predictors.

**Level 1 - Predictors:**
Pre-injury: RBRI (Attention, parent version), VABS, Rowe-E.
Injury/Development: Medical Questionnaire (Severity, injury age)
Psychosocial: Epidemiological Questionnaire (SES, intact family)

**Level 2 - Predictors:**
Attention: Acute stage:
Sustained attention: CPT (Total number correct)
Selective attention: LCT (Total number correct)
Shifting attention: CNT (Time taken Trial 4)
Processing speed: PS: (Index from WISC-111)

**Level 3 - Outcome measures:**
Reading: WRAT-3 (standardised score)
Spelling: WRAT-3 (standardised score)
Arithmetic: WRAT-3 (standardised score)
Comprehension: WIAT (standardised score)
Adaptive functioning: VABS (standardised score)

11.2.2: Statistical analysis

A series of Stepwise Multiple Regressions were conducted in order to examine predictors of the different components of Figure 11.1, with the ultimate goal being the prediction of educational and adaptive outcomes. Predictors that were highly correlated were removed from the analysis.
11.3: Results

(A) Predictors of attentional measures

To investigate the possible predictors of the attentional components (sustained attention, selective attention, shifting attention, speed of processing), a series of Stepwise Multiple Regressions were undertaken. The predictors were divided into 3 domains, and each domain was investigated to determine whether it predicted performance on the attentional measures. Predictors were entered as follows - (a) Pre-injury predictors - RBRI, VABS, Rowe-E (Reading, Spelling, Arithmetic, Comprehension); (b) Injury/Developmental predictors - Severity, age at injury; (c) Psycho-social predictors - SES, Intact family (see below and Table 11.1 for results).

Sustained attention:

With regard to the Pre-injury Domain, sustained attention was best predicted by pre-injury Reading Accuracy ability and the pre-injury VABS, with these variables explaining 11% of the variance. When analysing the Injury/Developmental Domain, sustained attention was best predicted by Injury Age and Severity, and these variables explained 24% of the variance. Thirdly, the Psychosocial Domain was not significant in the prediction of sustained attention. Of importance is the contribution of Pre-injury Reading Accuracy and VABS in predicting attentional outcomes, suggesting that a child’s pre-morbid ability, in both educational and every-day living skills, assist in the prediction of a child’s ability to maintain attention over time in the acute stage.

Selective attention:

When investigating predictors of selective attention, the Pre-injury and Psychosocial Domains did not provide any significant results, suggesting that performance in this area is more reliant on variables in the Injury and Developmental Domain. Results revealed that Age at Injury explained 33% of the variance, and when combined with Severity, these variables explained 38% of the variance. Since the selective attention task is not a standardised measure, and requires speed as well as accuracy, that it is not surprising that injury age influences performance on this task.
Shifting attention:

The predictors of shifting attention were a little different to those of the sustained and selective categories. Once again, the Pre-injury Domain did not provide any significant predictors, while for the Injury/Developmental Domain, GCS and Injury Age explained 28% of the variance. From the Psychosocial Domain, the Intact Family variable also explained 7% of the variance. The significance of the Intact Family variable suggests factors, external to the child, may also contribute to performance on given tasks.

Processing Speed:

With regard to processing speed, as measure by the WISC-111, and so a standardised measure, the best predictor was Severity and this explained 20% of the variance. The Processing Speed Tasks require speed and visuo-motor integration skills, and these factors may have been compromised in the severe TBI children.

Table 11.1: Significant predictors of attention during the acute stage post-TBI

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Sustained attention</td>
<td></td>
<td>0.28</td>
<td>0.34</td>
<td>0.35</td>
<td>0.50</td>
</tr>
<tr>
<td>Pre-injury</td>
<td>Rowe-E</td>
<td>0.28</td>
<td>0.08</td>
<td>5.14</td>
<td>0.03</td>
</tr>
<tr>
<td>VABS</td>
<td></td>
<td>0.34</td>
<td>0.11</td>
<td>2.59</td>
<td>0.11</td>
</tr>
<tr>
<td>Injury/Developmental</td>
<td>Injury age</td>
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<td>0.13</td>
<td>9.75</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Severity</td>
<td>0.50</td>
<td>0.24</td>
<td>10.11</td>
<td>0.00</td>
</tr>
<tr>
<td>Selective attention</td>
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<td>0.58</td>
<td>0.33</td>
<td>34.40</td>
<td>0.00</td>
</tr>
<tr>
<td>Injury/Developmental</td>
<td>Injury age</td>
<td>0.58</td>
<td>0.33</td>
<td>34.40</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Severity</td>
<td>0.61</td>
<td>0.38</td>
<td>5.34</td>
<td>0.02</td>
</tr>
<tr>
<td>Shifting attention</td>
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<td>0.38</td>
<td>0.15</td>
<td>11.74</td>
<td>0.00</td>
</tr>
<tr>
<td>Injury/Developmental</td>
<td>Severity</td>
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<td>0.15</td>
<td>11.74</td>
<td>0.00</td>
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<tr>
<td></td>
<td>Injury age</td>
<td>0.52</td>
<td>0.28</td>
<td>12.13</td>
<td>0.00</td>
</tr>
<tr>
<td>Processing speed</td>
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<td>0.42</td>
<td>0.18</td>
<td>15.30</td>
<td>0.00</td>
</tr>
<tr>
<td>Injury/Developmental</td>
<td>Severity</td>
<td>0.42</td>
<td>0.18</td>
<td>15.30</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Injury age</td>
<td>0.45</td>
<td>0.20</td>
<td>2.37</td>
<td>0.13</td>
</tr>
</tbody>
</table>
(B) Predictors of educational and adaptive outcomes

A number of variables were analysed as possible predictors of reading, spelling, arithmetic comprehension and adaptive skills at 24 months post-injury. Since the injury/developmental variables were most successful in predicting attentional outcomes, and psychosocial the poorest, predictor variables were entered in the following order into the Stepwise Multiple Regression: severity, Rowe-E, RBRI, VABS, Sustained attention, Selective attention, Shifting Attention, Processing Speed, SES, and Intact Family (see Table 11.2)

Reading Accuracy:

With regard to reading accuracy, the Rowe-E (pre-injury reading) was the strongest predictor, and explained 47% of the variance. When Processing Speed and Shifting Attention were also included, then 55% of the variance was attributed to these variables together. These findings strongly suggest that pre-injury reading ability strongly influences outcome in this area at 24 months post-injury, with Processing Speed and Shifting Attention also adding to the predictive power.

Spelling:

When considering spelling ability, again the Rowe-E (pre-injury spelling) resulted as the strongest predictor, explaining 35% of the variance. Another significant predictor was the VABS, with both of these variables explaining 47% of the variance. Again, these results stress the influence of pre-injury skills on later recovery and performance post-TBI.

Arithmetic:

Predictors of arithmetic were greater in number. Again the Rowe-E (pre-injury arithmetic) was the best predictor, explaining 27% of the variance. However, also of importance were Processing Speed (combined with the Rowe-E it explained 37% of the variance) and Severity, with 42% of the variance explained by all three
variables. The RBRI and shifting attention also made a contribution, and all together, these successful predictors explained 49% of the variance. These results suggest that while post-injury performance in the arithmetic area is strongly influenced by pre-injury ability in arithmetic, processing speed (the efficiency with which information is inputted and outputted), the severity of the injury, and attentional variables (pre-and-post) are all important factors that influence one’s ability in performing well in the arithmetic area, stressing the importance of both pre-and-post injury factors in this domain.

**Listening Comprehension:**

The variables were not as successful in predicting Reading Comprehension. However, as expected, the best predictor was the Rowe-E (pre-injury comprehension), and this predicted 10% of the variance.

**Adaptive Functioning:**

With regard to predictors of adaptive functioning at 24 months post-injury, analysis revealed that Processing Speed was the best predictor (27% of the variance), followed by the VABS and Selective Attention, with all variables explaining 45% of the variance. Adaptive functioning appears to require efficient speed of processing information, as well as one’s pre-injury adaptive skills and the ability to focus on relevant information and ignore distracters.
Table 11.2: Significant predictors of educational/adaptive outcomes 24 months post-TBI

<table>
<thead>
<tr>
<th>Predictor</th>
<th>r</th>
<th>r²</th>
<th>F</th>
<th>p</th>
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<tr>
<td><strong>Reading accuracy</strong></td>
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<tr>
<td>Rowe-E</td>
<td>0.69</td>
<td>0.47</td>
<td>46.39</td>
<td>0.00</td>
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<tr>
<td>PS</td>
<td>0.72</td>
<td>0.52</td>
<td>5.66</td>
<td>0.02</td>
</tr>
<tr>
<td>Shifting atten.</td>
<td>0.74</td>
<td>0.55</td>
<td>2.23</td>
<td>0.14</td>
</tr>
<tr>
<td><strong>Spelling</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rowe-E</td>
<td>0.59</td>
<td>0.35</td>
<td>28.24</td>
<td>0.00</td>
</tr>
<tr>
<td>VABS</td>
<td>0.69</td>
<td>0.47</td>
<td>11.70</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Arithmetic</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rowe-E</td>
<td>0.52</td>
<td>0.27</td>
<td>18.81</td>
<td>0.00</td>
</tr>
<tr>
<td>PS</td>
<td>0.61</td>
<td>0.37</td>
<td>8.05</td>
<td>0.01</td>
</tr>
<tr>
<td>Severity</td>
<td>0.65</td>
<td>0.42</td>
<td>4.72</td>
<td>0.04</td>
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<td>RBRI</td>
<td>0.67</td>
<td>0.46</td>
<td>3.12</td>
<td>0.08</td>
</tr>
<tr>
<td>Shifting atten.</td>
<td>0.70</td>
<td>0.49</td>
<td>3.05</td>
<td>0.09</td>
</tr>
<tr>
<td><strong>Comprehension</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rowe-E</td>
<td>0.31</td>
<td>0.10</td>
<td>5.44</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>Adapt. functioning</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PS</td>
<td>0.52</td>
<td>0.27</td>
<td>18.20</td>
<td>0.00</td>
</tr>
<tr>
<td>VABS</td>
<td>0.63</td>
<td>0.39</td>
<td>9.9</td>
<td>0.00</td>
</tr>
<tr>
<td>Select. atten.</td>
<td>0.67</td>
<td>0.45</td>
<td>5.12</td>
<td>0.03</td>
</tr>
</tbody>
</table>

11.4: Discussion

The results from the present study provide some support for the model proposed in Figure 11.1. The analyses provided by the series of Stepwise Multiple Regressions suggest that both pre-and-post injury variables are predictive of outcome at 24 months post-TBI.
Predictors of attentional measures

Regression analysis provided an insight into the possible predictors of attentional outcome during the acute stage. With regard to sustained attention, the Injury/Developmental Domain was the most successful in predicting outcome. However, Severity, Injury age and Pre-injury Reading Accuracy and VABS, were all significant predictors of outcome. These results suggest that a child’s premorbid level of functioning in both educational and everyday living skills has an affect on sustained attention post-injury. Not surprisingly, the severity of injury, especially during the acute stage, also has an effect on outcome. The sustained attention task is not a standardised task, therefore it follows that age at injury is also an important predictor of outcome, where younger children may be at a disadvantage when completing the task. Unexpectedly, the RBRI was not a significant predictor of outcome, perhaps suggesting that parents are not always able to accurately rate their child’s performance in a particular area.

When considering Selective and Shifting Attention, the pre-injury Domain did not result in significant predictors of outcome. However, in both areas, severity of injury and injury age were the best predictors of outcome., again high-lighting that on these unstandardised tests the child’s age will affect the level of importance. The Intact Family variable was also successful in predicting Shifting Attention. This may suggest that the way a family interacts and how decisions are made, may affect one’s ability to shift cognitive set and to adapt a more flexible mind-set.

The Injury/Developmental Domain was the most successful in predicting Processing Speed. Severity of injury best predicted outcome on the Processing Speed measure from the WISC-111. These tasks require a combination of skills including speed, accuracy, memory, decision-making and visuo-motor integration, suggesting that a severe TBI child will be compromised in one or more of these areas during the acute phase post-injury, resulting in poorer performance.
Predictors of educational and adaptive outcomes

With regard to Reading Accuracy, Pre-injury Reading Ability and Processing Speed in the acute stage were the best predictors of outcome, suggesting that both pre-injury factors and the ability to efficiently process information, play a part in predicting reading outcome. As mentioned earlier, in Chapter 10, reading skills are consolidated in the early primary years, and so may be less vulnerable following TBI. Similarly, spelling ability at 24 months was best predicted by Pre-injury Spelling ability and the VABS. Again, these results reveal the importance of pre-injury factors when predicting outcome following injury. As anticipated, Pre-injury Arithmetic ability and Processing Speed were again significant predictors of Arithmetic ability at 24 months post-TBI. Processing Speed may be defined as the underlying factor in an efficient attentional/processing system, therefore its importance is not surprising. To complete arithmetic calculations, an efficient system to input, output and manipulate data is essential, and if these processes are completed in an inefficient way, then memory, the mental manipulation of information and attention may be compromised, therefore high-lighting the importance of an efficient system where these processes are carried out quickly and accurately. Arithmetic requires the integration of a number of skills, therefore it is not surprising that injury severity and attentional factors are also predictive in this area. Reading comprehension was best predicted by Pre-injury Reading Comprehension skills, suggesting that as in Reading Accuracy, this skills may have been established by much of the sample prior to their injury, and so post-injury performance is a reflection of pre-injury ability.

Unexpectedly, Processing Speed resulted as the best predictor of Adaptive Functioning at 24 months post-injury. As expected the VABS was also a strong predictor of outcome in this area, followed by Selective Attention. As mentioned above, efficient speed of processing is an important underlying factor in both educational and every-day living ability, as it determines the efficiency of mental processes. These results also indicate that a child's adaptive functioning following TBI is affected by pre-injury abilities in the areas measured by the VABS. The importance of Selective Attention may be in the ability of the child to focus on
important details/facts while ignoring distracters when involved in everyday interactions, that is being able to filter out what is irrelevant to a given situation and so prioritise and focus on key elements.

Conclusions

The aim of this study was to investigate predictors of educational and adaptive outcome using the model presented in Figure 11.1. With regard to the first step in the model, that is predictors of attentional measures, statistical analysis did support the model where a number of variables in the predictive domains did predict attentional skills in the acute stage post-TBI. When considering the next step, that is, whether attentional measures also predict educational and adaptive functioning, again, the model was supported to a degree, suggesting that both pre-injury as well as attentional factors predict functional outcome, indicating that a complexity of predictors are involved in outcomes at 24 months post-injury.
Chapter 12:

General Conclusions

12.1: Summary

The present study has investigated three groups of children who sustained a traumatic brain injury between the ages of 8-12. The children were assessed using a battery of tests measuring skills in areas including intellectual ability, attention, memory, learning and educational ability. The study included a range of children who were categorised as having sustained a mild, moderate, or severe closed head-injury. As the study was longitudinal in design, it provided the opportunity to monitor the recovery of a number of skills, in each of the TBI groups, over a twenty-four month period post-TBI.

Results generally revealed that while the severe TBI group showed most recovery over the 24 month period, they were performing below their peers at this stage in the recovery process. Results also showed that while the mild, moderate and severe TBI groups at times performed similarly on the more simple tasks, it was when task complexity increased that the severe TBI group was not able to maintain the same level as the mild and moderate groups. Not all skills developed/recovered at the same rate, suggesting the role of developmental spurts for certain skills at different ages.

With regard to predictors of outcome, the results from Chapter 11, when testing Figure 11.1, suggest that injury/developmental factors are the best predictors of attentional skills (sustained, selective, shifting attention and processing speed) during the acute stage post-TBI. When investigating possible predictors of functional outcome (educational and adaptive skills) at 24 months post-injury, the results indicate that pre-injury factors (especially in the educational areas) and speed
of processing, which is thought to underpin the efficiency of the attentional system (Mirskey et al., 1991) are the most significant predictors, high-lighting the importance of both pre-and post injury factors when predicting outcome.

12.2: Aims

The aims of this research study were all fulfilled. That is, information processing skills were investigated in the mild, moderate and severe TBI groups and deficits were identified. Furthermore, the profiles of recovery for intellectual, information processing, educational and adaptive skills were documented. The possible relationship between attentional deficits and functional outcomes was also investigated, leading to identification of children who may be at risk for future difficulties in intellectual, functional and social areas.

12.3: Limitations of study

A limitation of the study is the lack of a control group. However, since the main focus of the study was to map the recovery of skills, in a number of cognitive areas, the inclusion of a control group was not crucial. Each TBI group became their own control as performance was compared over time. Furthermore, much previous research has indicated that children who have sustained a mild TBI do not present with deficits, and so may be considered a control group against which to compare children who have sustained moderate or severe injuries. According to a recent paper (Satz, P., Zaucha, K., McCleary, C., Light, R., Asarnow, R., & Becker, D, 1997), a study was considered methodologically strong if it met at least four of the following criteria: (1) control group; (2) longitudinal design with follow-up assessment; (3) clear definition of injury- without pooling injury severity groups; (4) substantial number of cases; (5) standardised tests; (6) control for pre-injury risk factors. While the current study did not fulfill criteria (1), it did meet the other criteria outlined.
Another possible limitation of the study is the sample size. While the sample size was adequate, more sophisticated statistical techniques may have been used (e.g. structural equation modeling) if the number of children in each severity category was larger. However, as longitudinal studies are prospective in nature, the sample size is determined by the number of children who sustain an injury over a designated period of time, not allowing the researcher the opportunity to increase numbers unless subjects are recruited for an unlimited amount of time, an option that is not often available.

12.4: Future directions

Results from the current study provide evidence of persistent difficulties 24 months post-injury. These results have clinical implications with regard to the amount of follow-up provided for children following TBI. It is essential that children are followed closely and for a longer period after sustaining a close head-injury. While some deficits may become apparent immediately after an injury, some will show recovery over time, yet often not to the expected level, suggesting ongoing difficulties for the child. Furthermore, due to the developmental nature in the acquisition of cognitive skills, other areas of skill deficit may only emerge when the child is of a particular age, and this will go unnoticed for a period of time. Therefore, follow-up consultations and assessments must be made available in order to address these issues and to prevent the emergence of secondary problems. Adolescence and adulthood are also times of transition, and again, services at this time would be most beneficial for this population.

The results from this study may be used to provide further education to a number of populations. Children who have sustained a TBI often present as a challenge in the complex classroom environment. Unless staff are aware of the limitations of the child, and of the best strategies and interventions to utilise, then both the child and the staff are at a disadvantage. The understanding of what
happens at the time of an injury and the awareness of strategies to use when ongoing difficulties are present, can often lead to an environment that is catering to the child’s current needs, while also reducing the possibility of secondary behavioural, emotional and social difficulties.

This information may also be disseminated to medical staff who often have much contact while children are in hospital, up to the stage where children are discharged and may return for reviews. During this acute time TBI children often present as ‘recovered’ in the physical sense. However, it is only as time passes and the child returns to school that difficulties become evident. Medical personnel often benefit from the feedback of a neuropsychological assessment, as it allows them the opportunity to then investigate both ‘physical’ recovery and the ongoing recovery of function.

Parents also appreciate some information on what may happen following TBI. This allows the parents to monitor the recovery of their child and to seek assistance if any common areas of difficulty (e.g. attentional difficulties) become evident. Parents feel more confident and empowered if they receive some relevant information about head-injuries and possible persisting difficulties. Of utmost importance is also the understanding of any cognitive changes realised by the child. Children often report that their memory is not as strong, or that a particular school subject is now ‘hard’. Children often feel better about these changes if they have some understanding of what happened and of the recovery process, allowing them time to both improve these skills and/or accept that a certain skill area will remain more difficult post-TBI.

Knowledge about the seriousness of TBI and the awareness of possible persisting difficulties may also assist in changing community behaviours. That is, parents will be more active in ensuring children have seat belts fastened while in the car. Children may be taught of the necessity of wearing bicycle helmets when
riding or roller-blading. As more information is disseminated to the community, adults are in a better position to try and prevent TBI from occurring to their child.

It is essential that more longitudinal research is undertaken in this area. Children who have sustained injuries at different ages will most likely present with a different pattern of strengths and weaknesses. Furthermore, children who have had a more diffuse injury, will also present differently to those who have sustained a more focal injury. All these factors are important when attempting to predict outcome for these children, and in order to identify children at most risk for ongoing cognitive, behavioural, social and emotional difficulties. It is only by investigating a large number of children, over time, that answers to many questions can become clearer.
Bibliography


Koskiniemi, M., Kyykka, T., Nybo, T., & Jarho, L. Long-term outcome after severe brain injury in preschoolers is worse than expected. *Archives of Pediatric and Adolescent Medicine, 149*, 249-254.


*Cortex, 6*, 121 - 127.


*Journal of Head Trauma Rehabilitation, 6*(1), 35 - 46.


*Neuropsychology Review, 2*(2), 109 - 145.


cchildren with traumatic brain injury. Archives of Clinical Neuropsychology,
11(2), 147-153.

San Antonio, TX: The Psychological Corporation.

Version III. (Australian Adaptation) New York: The Psychological
Corporation.

Antonio: The Psychological Corporation USA.

children: Views from developmental psychology. Development

children: Potential efficacy of tasks in discriminating clinical groups.
Developmental Neuropsychology, 10(1), 27-38.


pediatric head injury: A developmental prospective.

Wilson, B. (1992). Assessment and management of memory problems. In Von
Steinbuchel, Von Gramon, D.Y. & Poppel, E. (Eds.), Neuropsychological
Rehabilitation, Springer and Verlag.

Wilson, J.T.L., Wiedmann, K.D., Hadley, D.M., Condon, B., Teasdale, G., &
Brooks, D.N. (1988) Early and late magnetic resonance imaging and


APPENDIX 1
(1) ACCIDENT DETAILS: .................................................................
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(9) DRUGS: .................................................................

(10) SEIZURES:
(a) During admission: ..................................................
(b) Since discharge: ..............................................

(11) NEUROLOGICAL SIGNS:
(a) On admission: ..................................................
(b) On discharge: .............................................
Child's Name: ................................................

Sex: .......... (Male or Female)

Date of birth: ....../....../....

Address: ..................................................

..................................................

Telephone Number: ............

School: ................................................

School Grade/Year: ......................

Family Data:

a. Father's occupation: ......................

b. Father's educational level: ..............

c. Mother's occupation: ......................

d. Mother's educational level: ..............

e. Number of siblings: ......................

f. Language/s spoken at home: ..............

................................................

Family Tree: (Insert details or a diagram):
Has your child had any of the following problems prior to or after the head injury?

PLEASE CIRCLE YES OR NO

IF "YES" please specify in the space provided.

(1) MEDICAL CONDITION: YES/NO

PRIOR: ..............................................................

AFTER: .............................................................

(2) BEHAVIOURAL PROBLEMS: YES/NO

PRIOR: ..............................................................

AFTER: .............................................................

(3) LANGUAGE PROBLEMS: YES/NO

PRIOR: ..............................................................

AFTER: .............................................................

(4) VISUAL PROBLEMS: YES/NO

PRIOR: ..............................................................

AFTER: .............................................................

(5) MEMORY PROBLEMS: YES/NO

PRIOR: ..............................................................

AFTER: .............................................................

(6) SLEEPING PROBLEMS: YES/NO

PRIOR: ..............................................................
EPIDEMIOLOGICAL QUESTIONNAIRE:

(7) COORDINATION PROBLEMS: YES/NO

PRIOR: .................................................................

AFTER: .................................................................

(8) POOR INTERACTION WITH PEERS OR SIBLINGS: YES/NO

PRIOR: .................................................................

AFTER: .................................................................

DEVELOPMENTAL MILESTONES:

a. Age when your child crawled (approx.): ........(months)

b. Age when your child walked (approx.): ........(months)

c. Age when your child first put words together (approx.):
   ........(months)

d. Child’s preference of hands: ..............(Left/Right/Both)

e. Did you have any concerns regarding your child’s
developmental progress?: ...............(Yes/No)

f. Has the family unit changed in the last 2 years?:
   ............(Yes/No)
   If yes, please specify: .....................
II. BEHAVIOURAL RATING INVENTORY

TODAY'S DATE: __________

Parents, for each of the following paired behavioural statements, please mark a cross over the dot (e.g., ☑) which is nearest the statement which best describes the behaviour of the child **BEFORE** THE INJURY/ACCIDENT.

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Cannot concentrate on any particular task; easily distracted</td>
<td>☑</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>2</td>
<td>Eager to learn; curious and inquiring</td>
<td>☑</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>3</td>
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<td>☑</td>
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</tr>
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<td>Irritable, 'touchy', 'cranky'</td>
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</tr>
<tr>
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<tr>
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</tr>
<tr>
<td>12</td>
<td>Restless; fidgety; can't sit still</td>
<td>☑</td>
<td>☐</td>
<td>☐</td>
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<td>☐</td>
<td>☐</td>
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<tr>
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<td>Purposeful activity</td>
<td>☑</td>
<td>☐</td>
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<td>16</td>
<td>Rough or aggressive with other children - usually unprovoked</td>
<td>☑</td>
<td>☐</td>
<td>☐</td>
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<tr>
<td>17</td>
<td>Parents have no difficulty in controlling child's behaviour</td>
<td>☑</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>18</td>
<td>Frequent temper tantrums</td>
<td>☑</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
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<tr>
<td>19</td>
<td>Has difficulty in settling down to sleep</td>
<td>☑</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
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<tr>
<td>20</td>
<td>Undisturbed, restful sleep</td>
<td>☑</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
jeland Adaptive Behavior Scales: INTERVIEW EDITION Survey Form

Chronological age

Supplementary norm group (if applicable)

SCORE SUMMARY

SUBDOMAIN

Receptive
Expressive
Written

PERSONAL

Domestic
Community

LIVING SKILLS DOMAIN

Interpersonal Relationships
Play and Leisure Time
Coping Skills

GRoss

Fine

TOR SKILLS DOMAIN

SUM OF DOMAIN

STANDARD SCORES

APTIVE BEHAVIOR COMPOSITE

SCORE PROFILE

COMMUNICATION DOMAIN

LIVING SKILLS DOMAIN

SOCIALIZATION DOMAIN

MOTOR SKILLS DOMAIN

APTIVE BEHAVIOR COMPOSITE

OPTIONAL

MALADAPTIVE BEHAVIOR DOMAIN

(Administer for ages 5-0-0 and older)

Additional interpretive information (see Chapters 5 and 6 in the manual)

Reinancements

©1984 American Guidance Service, Inc., Circle Pines, MN 55014-1796. No part of this form may be photocopied or otherwise reproduced. Printed in the U.S.A. For additional forms call or write AGS: 4201 Woodland Road, Circle Pines, MN 55014-1796; toll-free 1-800-328-2560, in Canada, 1-800-263-3558. Ask for item # 5015 (25 per package).
### II. BEHAVIOURAL RATING INVENTORY

**MILD'S NAME:** ___________________________  **TODAY'S DATE:** ___________________________

**TEACHERS**, for each of the following paired behavioural statements, please mark a cross over the dot (e.g., ☑️) which is nearest the statement which best describes the behaviour of the child **BEFORE** THE INJURY / ACCIDENT?

<p>| | | | | | | |</p>
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</table>
Please complete the following scale investigating the child’s school performance prior to the head-injury:

Please list any other academic subjects/areas which are applicable and rate the child’s performance on each subject/area where: 0=Not applicable 1=Far below grade level 2=Somewhat/mildly below grade level 3=At grade level 4=Somewhat/mildly above grade level 5=Far above grade level

**SUBJECTS:**

1. English  
2. Reading accuracy  
3. Reading comprehension  
4. Spelling  
5. Mathematics

**RATING:**

1. ( )  
2. ( )  
3. ( )  
4. ( )  
5. ( )

Other:

6. ( )  
7. ( )  
8. ( )  
9. ( )  
10. ( )

Any other comments?
LETTER CANCELLATION TEST.

INSTRUCTIONS: 1) CROSS OUT ALL THE C'S AND E'S.
2) WORK AS QUICKLY AS YOU CAN
3) STOP WHEN I TELL YOU TO STOP.

(TIME THEM FOR 1 MINUTE)

BEIFHEHFEGETICBDACHFBEDACDACAFICICFEBAFEAFCFCCHBDCFGHE
CAHFACDCFEHBFCADEHAEIEGDEGHBCCACGCIIECIIEFHIICDBCGFDEBAG
EBCAFCBEHFAEFEGCHGDHDEHBAGDACHEBABEDGCDADFBCBIFEAADCBEEACG
CDGACHEFBACFEABFCHDFECGACBEBDCAFHEHEFDFICHBIEBCAHCDDEFB
ACBCGBTEHACAPCICABEGFBEFAEABGCFCACDBEDBCHEFEDHCAIEFEG
EDHBCADGEADFEBEIGACGEDACHGEDCABAEFBCDHDACGBEHCDFEHAIIE
TRAIL MAKING

Part B

SAMPLE

Begin 1

End 4

3

2

A

D

B

C
Continued on next page
Yesterday Peter / who was / seven years old / went down / to the river / to fish. / He took / his dog Prince / with him. / The river / had overflowed / its banks / after the / rainy weather. / Peter slipped / and fell into / deep water. / He would have drowned / if the dog / had not dived in / and helped him / to reach the shore.

John / was a boy / who liked apples / especially if / they were stolen. / One dark night / he went / into an orchard / picked what he / thought was / an apple / and bit his teeth / in it. / It was / however / a very unripe pair / and his loose / front tooth / stuck in the fruit. / Now he only / steals apples / in the daytime.
**Block Span:**

**Scoring Sheet:**

I am going to tap these blocks with care and when I am finished, tap them in the same order.

<table>
<thead>
<tr>
<th>Trial 1</th>
<th></th>
<th>Trial 2</th>
<th></th>
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<td>612</td>
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<td>3417</td>
<td></td>
<td>6158</td>
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<td>84239</td>
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<td>52186</td>
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<tr>
<td>538712469</td>
<td></td>
<td>426917835</td>
<td></td>
</tr>
</tbody>
</table>

→ Score as in WISC-R, just do forward. **Total**

→ Stop when both blocks are tapped incorrectly.
Complex Figure of Rot
(Used for Recall)
## WRAML Wide Range Assessment of Memory and Learning
### Examiner Form

**NAME:** __________________________  **SEX:** M  F

**SCHOOL:** _________________________  **GRADE:** ______

**REFERRED BY:** ___________________  **EXAMINER:** __________

**DATE OF EXAM:** YR. _____ MO. _____ DAY _____

**BIRTHDATE:** YR. _____ MO. _____ DAY _____

**AGE:** YR. _____ MO. _____ DAY _____

<table>
<thead>
<tr>
<th>Subtests</th>
<th>Raw Score</th>
<th>Verbal</th>
<th>Visual</th>
<th>Learning</th>
<th>WRAML Index Scores</th>
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<tr>
<td>Picture Memory</td>
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<td>Design Memory</td>
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<td>Verbal Learning</td>
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<tr>
<td>Story Memory</td>
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<td>Finger Windows</td>
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<td>Sound Symbol</td>
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<td>Sentence Memory</td>
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<td>Visual Learning</td>
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<td>Number/Letter</td>
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</table>

**Sum of Scaled Scores:**

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<thead>
<tr>
<th>Verbal Memory Index</th>
<th>(Sum of Verbal Scaled Scores)</th>
<th>Index</th>
<th>%ile</th>
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<tbody>
<tr>
<td>Visual Memory Index</td>
<td>(Sum of Visual Scaled Scores)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning Index</td>
<td>(Sum of Learning Scaled Scores)</td>
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<td></td>
</tr>
<tr>
<td>General Memory Index</td>
<td>(Sum of all Scaled Scores)</td>
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</tr>
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**WRAML Scales**

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<th>Scale Scores</th>
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<tbody>
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<td>Story Memory</td>
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<td>Sentences Memory</td>
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<tr>
<th>Verbal Learning Index</th>
<th>70</th>
<th>85</th>
<th>100</th>
<th>115</th>
<th>120</th>
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</thead>
<tbody>
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<td>Visual Memory Index</td>
<td>70</td>
<td>85</td>
<td>100</td>
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<td>120</td>
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<tr>
<td>Learning Index</td>
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<td>85</td>
<td>100</td>
<td>115</td>
<td>120</td>
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#### Delayed Recall Subtests

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<th>Subtests</th>
<th>Difference Scores</th>
<th>Atypical</th>
<th>Borderline</th>
<th>Low Avg.</th>
<th>Average</th>
<th>Bright Avg.</th>
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<td>Sound Symbol Recall</td>
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<td>Visual Learning Recall</td>
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<td>Story Memory Recog. Score</td>
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**Record Form**

**Summary**

<table>
<thead>
<tr>
<th>Child's Name</th>
<th>Sex</th>
<th>Year</th>
<th>Month</th>
<th>Day</th>
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<table>
<thead>
<tr>
<th>School</th>
<th>Grade</th>
<th>Examiner</th>
<th>Date Tested</th>
<th>Date of Birth</th>
<th>Age</th>
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<thead>
<tr>
<th>Referral Source</th>
<th>Reason for Referral</th>
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<table>
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<tr>
<th>Behavioral Observations</th>
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### Raw Scores

<table>
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<th>Standard Score</th>
<th>Confidence Interval</th>
<th>Percentile</th>
<th>Other</th>
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<td>Mathematics Reasoning</td>
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<td>Spelling</td>
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<td>Reading Comprehension</td>
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<td>Numerical Operations</td>
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<td>Oral Expression</td>
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<td>Written Expression</td>
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### Sum of Raw Scores

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<th>Reading</th>
<th>Mathematics</th>
<th>Language</th>
<th>Writing</th>
<th>Total Composite</th>
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<table>
<thead>
<tr>
<th>Standard Score</th>
<th>Confidence Interval</th>
<th>Percentile</th>
<th>Other</th>
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<tbody>
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### Total Composite

<table>
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<th>Total Composite</th>
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09-972076
Author/s:
Catroppa, Agata

Title:
A prospective analysis of the recovery of attention following paediatric traumatic brain injury

Date:
2000

Citation:

Publication Status:
Unpublished

Persistent Link:
http://hdl.handle.net/11343/35532

File Description:
A prospective analysis of the recovery of attention following paediatric traumatic brain injury

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