THE NATURE AND ASSESSMENT OF ATTENTIONAL FUNCTION FOLLOWING SEVERE TRAUMATIC BRAIN INJURY

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Declaration

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university, and that to the best of my knowledge and belief it does not contain any material previously published or written by another person, except where due reference is made in the text.

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Andrew Bate
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List of Abbreviations

ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
COAT	Covert Orienting of Attention Task
DAI	Diffuse Axonal Injury
EOG	Electro-occulargram
GCS	Glasgow Coma Scale
IQ	Intelligence Quotient
LOC	Loss of Consciousness
ms.	milliseconds
PASAT	Paced Auditory Serial Addition Test
PD	Parkinson's Disease
PSP	Progressive Supranuclear Palsy
PTA	Post Traumatic Amnesia
PTSD	Post Traumatic Stress Disorder
SAC	Supervisory Attentional Control
SDMT	Symbol Digit Modalities Test
TBI	Traumatic Brain Injury
TEA	Test of Everyday Attention
WMS-R	Wechsler Memory Scale – Revised

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Resultant Publications

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Conference Presentations

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ABSTRACT

Problems with attention are commonly reported following a severe traumatic brain injury (TBI). However, the nature of attentional function following severe TBI is not well understood and the measures used to assess attention are poorly developed. In particular, there are significant limitations associated with many measures of attention, namely their multi-factorial nature, lack of a theoretical underpinning, and poor ecological validity. In addition, little is known about the recovery of attentional function over time and the impact of attention upon memory function.

Using a broad range of both experimental and clinical measures this thesis undertook a comprehensive examination of the attentional function of persons who had sustained a severe TBI. The first two studies compared the performance of 35 severe TBI and 35 Control participants on the Covert Orienting of Attention Task (COAT). The COAT was presented in both the horizontal (Study 1) and vertical (Study 2) planes and utilised central directional cues. In order to assess divided attention, Study 1 and Study 2 also included a secondary Language task. A third study utilised a peripherally cued version of the COAT to compare exogenous and endogenous orienting processes with a different group of 11 severe TBI and 11 Control participants.

The performance of severe TBI (N = 35) and Control (N = 35) participants on a range of conventional neuropsychological measures (i.e. the Stroop, SDMT, Ruff Two's and Seven's Selective Attention Test, Digit Span, & PASAT) and the TEA was also examined, and compared against a self/significant other rating scale of everyday attentional behaviour (Study 4). A fifth study examined the recovery of attentional function following severe TBI by carrying out a cross-sectional analysis of the data obtained in Study 4. The TBI sample

within Study 4 was divided into two groups, with one group (N = 21) being within the first 12 months of their injury (Early TBI), and the second group (N = 14), more than 2 years post-injury (Late TBI). Thus, it was possible to directly compare the performance of these two groups who were at different stages in the recovery process. A further longitudinal study (Study 6) involved re-testing these two TBI groups ($N_{Early} = 11$, $N_{Late} = 9$) 12 months after the initial assessment. Finally, Study 7 examined the relationship between a series of attentional measures and the performance of both severe TBI (N = 33) and Control (N = 35) participants on the Wechsler Memory Scale – Revised (WMS-R).

Taken together, the studies within this thesis revealed the following main findings.

(1) In general, TBI participants were able to benefit from visual cues to orient their attention in much the same way as Controls. However, when given less time to process the cues, deficits in performance became evident. Thus, deficits in speed of information processing have a significant impact upon attentional function following severe TBI.

(2) The introduction of a secondary (Language) task resulted in an impairment in the orienting of attention in the TBI group under COAT (vertical) conditions, suggesting a deficit in divided attention following severe TBI.

(3) When a secondary Language (phoneme detection) task was presented in conjunction with the COAT, TBI participants displayed a significant deficit on the Language task, compared to Controls. This was in contrast to their performance on the Language task under single task conditions, where no such deficit was apparent. The dual task paradigm was therefore able to unmask attentional deficits that were not apparent under single task conditions.

(4) Of the TEA sub-tests, the Map Search, Telephone Search, Visual Elevator, Elevator Counting with Reversal, and Lottery sub-tests distinguished between the two groups, suggesting deficits in visual selective and sustained attention following severe TBI.

(5) With regard to the conventional neuropsychological measures, there were significant differences between the TBI and Control groups on the Stroop Colour Word, Stroop Modified Colour-Word, oral and written versions of the Symbol Digit Modalities Test (SDMT), Ruff Two's and Seven's Selective Attention test (total score), and the PASAT (1.2 and 1.6 sec. rate).

(6) The TEA sub-tests correlated more highly with the subjective reports of attentional problems given by significant others (on the Rating Scale of Attentional Behaviour) than did the conventional neuropsychological measures. Thus, performance on the TEA may more accurately reflect the level of attentional difficulties experienced by TBI sufferers in everyday life than the conventional neuropsychological measures.

(7) A principal components analysis of all of the TEA and conventional neuropsychological tests revealed a four component/factor structure of attention, largely consistent with previous studies. This factor structure included the factors of visual selective attention, attentional switching, sustained attention, and divided attention.

(8) Of all the attentional tests presented, the Map Search sub-test from the TEA was best able to discriminate between the severe TBI and Control groups.

(9) A longitudinal study revealed that there was some evidence of an improvement in attentional function beyond 2 years post-injury, with TBI participants producing a significantly greater improvement in performance on the Language task (under dual COAT conditions) than the Control group.

(10) There was some evidence to suggest that the memory deficits found in severe TBI may be a direct consequence of attentional problems.

While a number of measures thought to assess attentional processes were included within this thesis, only the COAT was able to differentiate between specific attentional and other cognitive processes. As a result, where differences occurred between the TBI and Control groups on these other measures, it was not possible to determine to what extent these differences were the result of attentional or other cognitive processes (e.g. speed of information processing or memory). However, in order to gain a better understanding of the nature and recovery of attentional function following severe TBI, it is essential that such distinctions can be made. Thus, the challenge now for clinicians and researchers is to focus upon the development of tasks capable of identifying specific attentional processes. It is suggested that this can best be achieved through using computer generated tasks, rather than relying upon the 'pencil and paper' format common to many neuropsychological tests.

The finding within this thesis of some recovery of attentional function in a group of TBI participants who were more than 2 years post-injury, challenged the commonly held view that little if any recovery occurs beyond this time. If this finding can be replicated in future studies it will have significant implications for rehabilitation planning and policy development.

Finally, the thesis concludes by making a number of recommendations regarding future research and the clinical assessment of attention following severe TBI. While past developments within the experimental literature have been slow to filter through to clinical practice, it is hoped that the growing consensus of opinion in support of the Posner model, and its associated components, will lead to closer ties between the research literature and clinical practice.

CHAPTER 1

TRAUMATIC BRAIN INJURY

1.1 Introduction

Traumatic brain injury (TBI) is now recognised as a major public health problem (Farmer, Gibler, Kavanaugh & Johnson, 2000; Guha, 2004; Jennett 1996; Levin, Benton, & Grossman, 1982; Miller 1996; Schouten et al., 2004). In 1982, the *Wall Street Journal* referred to TBI as a 'silent epidemic' (Klein 1982), reflecting a growing awareness of the human and economic costs of TBI. The following chapter provides an overview of TBI by examining the different types of TBI, levels of injury severity, epidemiology, neuropathology, and physical, cognitive and psycho-social sequelae. The chapter concludes by identifying a number of deficiencies in our current knowledge and understanding of TBI.

1.2 Traumatic Brain Injury

Traumatic brain injury is the most common form of brain injury (Fortune & Wen, 1999; Kurtzke, 1984). While there are many definitions of TBI (refer to Fortune & Wen, 1999 for a review), they all require that the injury is sustained after birth and that it is the result of either an impact to the head, or rapid accelerative, decelerative or rotational forces. In addition, TBIs can be classified in terms of whether or not the impact resulted in a penetration of the skull.

A penetrating (open) TBI occurs when an object enters the skull and tears the soft brain tissue in its path (Vogenthaler, 1987). Projectiles, such as bullets, may terminate in the brain, or may have sufficient velocity to continue their path and exit the skull on the opposing side (Levy, Davis, & Russell, 1998). Brain damage as a result of penetrating injuries tends to affect relatively localized areas of the brain, which results in fairly discrete and predictable deficits (Vogenthaler, 1987). However, more widespread damage can also occur as a result of the 'shock waves' generated by the projectile (Grubb & Coxe, 1978), particularly high velocity projectiles such as those fired by modern weaponry (Grafman & Salazar, 1987). A further complication of penetrating TBIs is that there is a significant risk of intracranial infection (Jennett & Teasdale, 1981).

Non-penetrating (closed) TBIs, on the other hand, do not involve any penetration of the skull. Rather, they result from the violent movement of the brain within the skull, which results in the compression, stretching and twisting of brain tissue (Vogenthaler, 1987). These forces are the result of either a blow to the head or the rapid accelerative/decelerative and rotational forces that are characteristic of high-speed motor vehicle accidents and 'roll-overs' (Hoschwender, 1988; Sweeney, 1992). Non-penetrating TBIs produce more diffuse brain damage than the more circumscribed lesions associated with penetrating TBI. As a result, non-penetrating TBIs often lead to a broader range of deficits than penetrating injuries (Vogenthaler, 1987). Non-penetrating TBIs are the most common form of TBI, accounting for more than 90 percent of all TBIs within the civilian population (Grafman & Salazar, 1987). Consequently, the remainder of this thesis focuses specifically upon this group.

1.3 Severity of Injury

The severity of a TBI can range from patients who remain in a prolonged coma or persistent vegetative state to those patients whose injuries are so mild that they do not attend a hospital for treatment (Jennett, 1996). Traditionally, TBIs have been classified as either mild, moderate or severe. Approximately 80% of TBIs are classified as mild, 8% to 10% as moderate, and around 10% as severe (Miller & Jones, 1990).

Injury severity is assessed using a variety of different measures. The Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974) is the most widely used method of assessing severity of injury (Rowley & Fielding, 1991). It assesses level of consciousness using clinician ratings of the patient's eye opening ability, as well as motor and verbal responsiveness (Teasdale & Jennett, 1974). Scores range from three to 15, with a score of eight or below indicating that a person is in a coma, which is defined by the failure to move in response to simple commands and the absence of comprehensible speech (Vogenthaler, 1987). The GCS has become generally accepted as a standard measure for assessing severity of injury in patients with impaired consciousness (Lezak, 1995). Table 1.1 outlines the injury severity classification criteria for both the GCS and period of unconsciousness. Despite its widespread use, the GCS has a number of limitations. For example, some patients may need to be intubated at the scene of the accident, making it impossible to elicit a verbal response. As a result, injury severity, as measured by the GCS, is often overestimated (Stocchetti et al., 2004). In addition, TBI patients may be intoxicated by alcohol or other drugs at the time of the accident, resulting in unreliable GCS scores (Stambrook, Moore, Lubusko, Peters & Blumenschein, 1993). Concerns have also been raised regarding the validity and reliability of the GCS and, in particular, the ability of inexperienced observers to use the scale reliably and accurately (Rowley & Fielding, 1991; Stein & Spettell, 1995).

TABLE 1.1 Injury Severity Classification Criteria for the Glasgow Coma Scale and Coma Duration

Classification	GCS		Loss of Consciousness
Mild	≥ 13	or	≤ 20 minutes
Moderate	9 – 12	or	No longer than within 6 hours of admission
Severe	≤ 8	or	> 6 hours after admission

Note. Patients with GCS ≤ 8 are considered to be in coma (Bond, 1986). A GCS of < 3 indicates death.

From Neuropsychological Assessment (p. 755), by M. D. Lezak, 1995, New York: Oxford University Press. Copyright 1995 by Oxford University Press. Adapted with permission.

Another method frequently used by investigators to determine severity of injury is based on the duration of post-traumatic amnesia (refer to Table 1.2). Post-traumatic amnesia (PTA) refers to a transient period of confusion and disorientation following TBI, and is characterised by an individual's inability to demonstrate a continuous memory of recent events (Russell & Nathan, 1946). A number of measures have been developed to assess PTA, such as the Galveston Orientation and Amnesia Test (Levin, O'Donnell, & Grossman, 1979), Westmead PTA Scale (Shores, Marosszeky, Sandenham, & Batchelor, 1986), and the Julia Farr PTA Scale (Forrester & Geffen, 1995). These measures provide a more accurate and reliable assessment of PTA than earlier estimates of PTA, which were based on retrospective interviews or the analysis of case notes (Forrester, Encel, & Geffen, 1994). PTA has been found to be one of the most reliable predictors of outcome following TBI (Greenwood, 1997).

TABLE 1.2 Estimates of Severity of Injury Based on PTA Duration

PTA Duration	Severity
< 5 minutes	Very mild
5 – 60 minutes	Mild
1 – 24 hours	Moderate
1 – 7 days	Severe
1 – 4 weeks	Very severe
More than 4 weeks	Extremely severe

Note. From Neuropsychological Assessment (p. 173), by M. D. Lezak, 1995, New York: Oxford University Press. Copyright 1995 by Oxford University Press. Reprinted with permission.

Finally, the duration of coma (loss of consciousness) has also been used as an indicator of severity of trauma. While the length of loss of consciousness has been found to correlate with outcome in moderate to severe TBIs (Livingston, Brooks, & Bond, 1985; Wilson, Vizor, & Bryant, 1991), it has been found to be a poor predictor of outcome in patients who suffer a relatively brief (i.e. up to 30 minutes) period of unconsciousness (Gronwall, 1989).

1.3.1 Mild Traumatic Brain Injuries

The terms 'mild head injury' and 'concussion' are often used interchangeably (Davidoff, Laibstain, Kessler, & Mark, 1988) to refer to an injury in which there is only a limited or no loss of consciousness. As outlined in Table 1.2, mild TBI sufferers have a GCS of ≥ 13 and a PTA duration of less than 60 minutes. Approximately 80% of all TBI's are considered mild (Miller & Jones, 1990). Originally, the term mild head injury was used where there was thought to be no structural damage to the brain and where patients were expected to recover with no residual effects (Merritt, 1959). However, neuropathological studies have detected microscopic lesions in patients with mild TBI (Alves, Macciocchi, & Barth, 1993; Blumbergs, 1997; Oppenheimer, 1968).

A direct impact to the head is not necessary for a mild injury to occur (Binder, 1986). Davidoff et al. (1988) suggests that the rotational forces exerted on the brain are the critical insults in most mild TBIs. As a result of their centripetal nature, these forces are greatest at the surface of the brain, particularly in the frontotemporal regions, and more diminished deep within the brain (Blumbergs, 1997; Davidoff et al., 1988). The predominantly frontotemporal involvement in mild TBI typically produces a symptom constellation that includes difficulties with attention/concentration, memory, abstract reasoning, and judgement (Kwentus, Hart, Peck, & Kornstein, 1985). It has been suggested that this constellation of symptoms may last from several weeks (Levin et al., 1987) to more than three months post-injury (Barth, Macciocchi, Giordani, & Jane, 1983). In addition, there are a small but significant number of patients who sustain an uncomplicated mild TBI and who continue to experience postconcussive symptoms more than 12 months after injury (Alves et al., 1993). Of particular concern is that these mild TBI sufferers may actually have undetected central nervous system lesions (Alves et al., 1993).

1.3.2 Moderate Traumatic Brain Injuries

Although eight to ten percent of all head injuries fall within this category (Miller & Jones, 1990), moderate TBI appears to have attracted less attention than the mild and severe forms (Rimel, Giordani, & Barth, 1982). Individuals who have had a moderate TBI have a score of nine to 12 on the GCS, and/or experience a period of post-traumatic amnesia of between one and 24 hours (McMillan & Glucksman, 1987). The incidence of focal lesions is higher than with mild TBI (Parker, 1990), as is the occurrence of mild interhemispheric disconnection (Levander & Sonesson, 1998).

Significant differences between mild and moderate TBI participants have been found on a number of measures of attention, memory, language, and executive functioning (Goldstein, Levin, Goldman, Clark, & Altonen, 2001). In addition, when compared to Control participants, moderate TBI sufferers have been found to display reduced speed of information processing, along with deficits in self monitoring and planning abilities (Lezak, 1995; McMillan and Glucksman, 1987). In terms of outcome, Rimel et al. (1982) found that two-thirds of their moderate TBI patients who had previously been working, had not returned to their employment.

1.3.3 Severe Traumatic Brain Injuries

While severe TBI accounts for less than 10% of the total number of head injuries, the level of disability and rehabilitation needs of this group far exceeds that of the mild and moderate TBI groups (Parker, 1990). Individuals within this group, by definition, have a GCS of ≤ 8 and/or a period of PTA greater than 24 hours.

Severe TBI's involve more widespread damage within the brain than occurs with mild to moderate injuries. Damage to the frontal and temporal lobes, along with diffuse axonal injury, are common features of severe TBI (Gennarelli, 1986). In addition, ventricular enlargement, resulting from the shrinkage of severely damaged neuronal tissue, is also often found following severe TBI (Bigler, Kurth, Blatter, & Abildskov, 1992). Frontal lobe damage in particular, with resultant executive function deficits, is a characteristic feature of severe TBI. These executive function deficits, which include impairments in self-direction, self-regulation, insight and awareness, have a significant impact upon the individual's ability to benefit from rehabilitation (Prigatano, 1987; 1991; Stuss, 1991). While there may be some resolution of the symptoms following mild and moderate TBI, the residual sequelae of severe

TBI is evident well beyond the first year post-injury. In particular, difficulties with memory, reduced speed of information processing, and divided attention have been consistently reported more than two years post-injury (Oddy, Humphrey, & Uttley, 1978; McKinlay, Brooks, Bond, Martinage, & Marshall, 1981; van Zomeren & van den Burg, 1985).

Improvements in medical technology and care are resulting in the survival of patients who would have previously died as a result of severe TBIs (Anderson et al., 1996; Oppermann, 2004). However, these increased survival rates are placing greater demands upon available rehabilitation resources. In addition, the demand for services by this group is further increased by the fact that the greatest proportion of severe TBI sufferers are young people whose life expectancy is not reduced by their permanent disability (Anderson et al., 1996). The needs of this group are therefore prominent within rehabilitation settings. Thus, after examining the epidemiology and neuropathology of TBI, in general, the remainder of this thesis will focus specifically upon severe TBI.

1.4 Epidemiology

Studies on the epidemiology of TBI are difficult to compare due to differences in the methodologies that are used to collect and analyse data. Although the majority of studies have used hospital admission data, some have used other sources, such as Accident and Emergency attendance figures or household surveys (Hillier, Hiller, & Metzer, 1997). The use of differing definitions of TBI and variations in the measures used to classify injury severity, have also made comparisons between studies difficult (Body & Leathem, 1996).

1.4.1 Incidence

Incidence is defined as the number of new cases occurring during a specified time period, as a proportion of the general population at risk (Body & Leathem, 1996). Annual incidence rates for TBI, based on hospital admission data for a number of countries including France, Norway, Scotland, Sweden, and the United Kingdom, are estimated to be in the range of 200 – 300 individuals per 100,000 of population per year (Tiret et al., 1990; Nestvold, Lundar, Blikra, & Lonnum, 1988; Scottish Head Injury Management Study, 1977; Johansen, Ronnnkvist, & Fugl-Meyer, 1991; Jennett & Macmillan, 1981). Fatality rates in these studies range between 1% and 2.8% of TBI admissions (Jennett, 1996).

Annual incidence rates across the United States during the 1970s and early 1980s ranged from 132 to 367 per 100,000 of population (Annegers, Grabow, Kurland, & Laws, 1980; Cooper et al., 1983; Jagger, Levine, Jane, & Rimel, 1984; Kalsbeek, McLaurin, Harris, & Miller, 1980). In contrast, a study carried out in the United States during 1991 revealed that approximately 750 per 100,000 of population sustained TBIs that resulted in a loss of consciousness (Sosin, Sniezek, & Thurman, 1996), a figure that is more than double the incidence rates reported in the earlier studies. However, this data was based upon a large-scale survey (the National Centre for Health Statistics' National Health Interview Survey) and not on hospital admission or discharge figures. Thus, it appears that a significant proportion of TBI sufferers never attend hospital emergency departments. These discrepancies in incidence rates highlight the problems caused by using different sources of information.

In order to address some of the difficulties encountered when comparing TBI studies, particularly those arising from different methodological approaches (e.g. hospital admission versus survey data), the United States' Centre for Disease Control and Prevention (CDC) published its *Guidelines for Surveillance of Central Nervous System Injury* (Thurman, Sniezek, Greenspan, & Smith, 1995). Seven states reviewed hospital discharge data for 1994 using these guidelines. The annual incidence rate in this sample was 90.9 per 100,000, which is considerably lower than the 200 –300 per 100,000 reported in previous studies (e.g. Tiret et al., 1986; Nestvold et al., 1988). Of this sample, approximately 14 per 100,00 died, 62 per 100,000 were hospitalised but were considered to have made a good recovery, and 24 per 100,000 were left with a long term disability (Thurman, Alverson, Dunn, Guerrero, & Sniezek, 1999). It has been suggested that the discrepancy between the findings of the Thurman et al., (1999) study and previous studies may be a reflection of either the success of injury prevention programs or recent changes in hospital admission policies that promote outpatient rather than inpatient care for less severe injuries (Thurman et al., 1999). When comparing the incidence rates of TBI to spinal cord injury, it has been found that there are 40 times as many TBIs each year in the United States as there are spinal cord injuries (Vogenthaler, 1987).

In Australia, incidence studies have been carried out separately for two different states, with rates of 310 per 100,000 being reported for New South Wales (Selecki, Ring, & Simpson, Vanderfield & Sewell, 1981; Badcock, 1987) and 322 to 400 per 100,000 in South Australia (Hillier et al., 1997; Woodward, Dorsch, & Simpson, 1984; Badcock, 1987). These incidence rates, based on hospital discharge data, exceed those reported in comparable studies in the US and Europe (i.e. 200 – 300 per 100,000 of population) and have been attributed to the heavy reliance upon long-distance travel between the remote areas of these states (Hillier et al., 1997). This hypothesis has been supported by the over representation of individuals from remote areas within the TBI incidence statistics for Australia (Hillier et al., 1997).

1.4.2 Aetiology

Data obtained from a U.S. hospital discharge study have revealed that transportation related accidents (including those involving motor vehicles, motor cycles, pedestrians, bicycles and recreational vehicles) accounted for 49% of all TBIs, falls for 26%, firearms for 10%, assaults not involving firearms for 8%, and ‘other causes’ for 7% of TBIs (Thurman et al., 1999). In

South Australia, transport accidents accounted for the majority (57%) of TBI admissions, followed by falls (29%) (Hillier et al., 1997). Assault (9%), drug abuse (1%), gunshot wounds (1%), and 'other' causes (3%) made up the remaining identifiable causes (Hillier et al., 1997). While there are similarities between the Australian and U.S. data, there is considerable variation between other countries. For example, road accidents account for 24% of TBI admissions in Scotland, and 90% of admissions in Taiwan (Jennett, 1996). Similarly, the proportion of TBI admissions due to assaults ranges from 1% of male TBI sufferers in France to 45% of male TBI sufferers in Johanesburg (Jennett, 1996).

1.4.3 Risk Factors

Epidemiological research consistently shows that sufferers of TBI are not a representative sample of the population as a whole (Vogenthaler, 1987). Two thirds of all TBIs involve males (Hillier et al., 1997; Thurman et al., 1999). Moreover, 70% of all TBIs occur in people under 30 years of age, with the majority occurring in the 15 to 24 year age bracket (Anderson & McLaurin, 1980; Rimel & Jane, 1984). An examination of the different age cohorts has revealed that transportation accidents are the most common cause of TBI in the 15 – 24 year age group, while falls are the most common cause of injury in the very young (Goldstein & Levin, 1990) and in persons aged over 75 years (Thurman et al., 1999). Alcohol and drug abusers are also at an increased risk, as are those with a history of psychiatric illness (Rimel & Jane, 1984). In fact, overall, alcohol has been found to be the most common risk factor in TBI (Body & Leathem, 1996). Interestingly, with regard to road traffic accidents, levels of intoxication have been found to be higher amongst injured pedestrians than injured drivers (Galbraith, Murray, Patel & Knill-Jones, 1976; Haddon, Valien, McCarroll, & Umberger, 1962).

TBI has itself been identified as a risk factor for a number of conditions. For example, following a single TBI, the risk to an individual of suffering a future TBI doubles, and if an individual suffers a second TBI, the risk of sustaining a further TBI is eight times that of the general population (Gaultieri & Cox, 1991). It is thought that this increased risk may be related to a reduction in reaction times caused by previous injuries, with the individual displaying an inability to take action quickly in response to expected spatial events that may put them at risk of a further injury (Cremona-Meteyard & Geffen, 1994). In addition to the increased risk of a future TBI, there is evidence that persons who have sustained a TBI also have a greater risk of developing a dementia of the Alzheimer's type (Albensi & Janigro, 2003; Lye & Shores, 2000; Rasmusson, Brandt, Martin, & Folstein, 1995; Schofield et al., 1997). It has been suggested that TBI initiates the deposition of the β-A4 amyloid protein in the brain, a protein that has been implicated in the formation of the diffuse plaques and neuritic tangles found in the cortex of sufferers of dementia of the Alzheimer's type (Mayeux, Ottman, & Tang, 1993).

1.5 Neuropathology: Primary and Secondary Injuries

Brain damage, as a result of TBI, typically occurs in two stages. The primary injury occurs at the time of the trauma, while the secondary injury results from a sequence of physiological processes set in motion by the primary injury (Grossman & Yousem, 1994). Blumbergs (1997) states that primary injuries are

> " *... the result of mechanical forces producing tissue deformation at the moment of injury. These deformations may directly damage the blood vessels, axons, neurons and glia in a focal, multifocal or diffuse pattern of involvement and initiate dynamic and evolving processes which differ for each component part*" (p. 39).

The two key mechanical forces responsible for primary injury in TBI are produced by either direct contact forces, such as when the head strikes or is struck by an object, or rapid accelerative/decelerative forces (Halliday, 1999), which are characteristic of high speed motor vehicle accidents. Direct contact forces can result in skull fractures and extradural haematomas, subdural haematomas and contusions (Grossman & Yousem, 1994). Damage at the site of the contact is often referred to as a *coup* injury (Katz, 1992). In addition, contact forces often result in the brain being forced against the opposite side of the skull to the point of contact (referred to as contre-coup injuries), resulting in further contusions (Katz, 1992). The majority of contre-coup contusions occur in the frontal and temporal lobes and the sylvian fissure region (Ommaya, Grubb, & Naumann, 1971). Rapid accelerative/decelerative forces induce violent head motions resulting in diffuse axonal injury, focal contusions, and subdural haematomas (Halliday, 1999). Furthermore, these forces are principally rotational (centripetal) in nature and, as a result, the forces are greatest at the surface of the brain, particularly within the frontotemporal areas, and are less deep within the brain (Davidoff et al., 1988; Wilson, 1990).

Secondary injuries have been described by Blumbergs (1997) as occurring

> "*... as a complication of the different types of primary brain damage and includes ischaemic and hypoxic damage, cerebral swelling, the consequences of raised intracranial pressure, hydrocephalus and infection*" (p. 39).

Secondary brain damage can involve a range of physiological processes that are the direct result of the primary injury. Haemorrhages are the most common cause of secondary damage (Adams, Graham, & Gennarelli, 1985). While preventing oxygen and other nutrients from reaching their target tissues, haemorrhages can also lead to haematomas (pooled mass of blood), which places pressure on the surrounding brain tissue (Vogenthaler, 1987). These haematomas may lie above (epidural), between, or below (subdural) the brain coverings, or within (intracerebral) the brain itself (Bostrom & Helander, 1986). Epidural haematomas result from local impact to the skull and laceration of the underlying dural arteries or veins

(Halliday, 1999). These haematomas most often occur in the temporal parietal region (Grossman & Yousem, 1994) and, if arterial in origin, can result in rapid neurological deterioration (Halliday, 1999). Subdural haematomas, on the other hand, are more likely to be caused by inertial than impact forces (Gennarelli & Thibault, 1982; Ommaya et al., 1971). Most subdural haematomas arise over the cerebral convexities but can also occur in the posterior fossa, middle cranial fossa, or along the tentorium (Grossman & Yousem, 1994; Halliday, 1999). Intracerebral haematomas may also form in conjunction with subdural haematomas, or separately deeper within the brain (Rosenthal, Griffith, Bond, & Miller, 1990).

Infection, in the form of a brain abscess or meningitis, is another secondary effect of TBI, occurring in 5% to 8% of severe TBI cases (Blumbergs, 1997). Intracranial pressure may also rise as a result of increased fluid retention and increased blood flow (Vogenthaler, 1987). TBI can additionally cause a widespread neuronal depolarization that triggers a large, nonspecific release of excitatory neurotransmitters including acetylcholine, glutamate, and aspartate (Miller, 1996). This widespread release results in an abnormal activation of receptors leading to transient, but also potentially permanent, alterations in neuronal function (Hayes, 1996). However, many of these secondary effects are reversible if intervention is rapid (Blumbergs, 1997).

1.5.1 Focal and Diffuse Damage

Injuries resulting from primary and secondary processes can lead to either focal or diffuse lesions. Focal brain damage refers to the damage at the site of the coup and contre-coup lesions. This damage is associated with quite discrete impairments of those functions mediated by the cortex at the site of the lesion (Katz, 1992). The anterior and inferior surface of the frontal and temporal lobes are particularly susceptible to focal damage as the brain abrades against the irregular surfaces of the skull (Blumbergs, 1997; Katz, 1992). Focal brain injuries include contusions, subdural haematoma, epidural haematoma, and intracerebral haematoma (Blumbergs, 1997). In situations where focal injuries result in a severe mass effect there is a substantial risk of secondary damage occurring (e.g. brain shift, herniation, and brainstem compression) (Parker 1990). As a result, surgical intervention is sometimes performed (Katz, 1992).

In contrast to focal damage, diffuse brain damage refers to more generalised damage that is widespread throughout the brain, and includes axonal injury, hypoxic damage, brain swelling, and vascular injury (Adams, Graham, Gennarelli, & Maxwell, 1991). The minute lesions and lacerations that are scattered throughout the brain as a result of diffuse injuries may eventually become the sites of scar tissue, degenerative changes, or small cavities (Povlishock & Christman, 1995). High velocity rotational acceleration has been found to be the most common primary cause of diffuse brain damage, leading to a stretching and shearing of axons (diffuse axonal injury – DAI) throughout the brain (Gennarelli et al., 1982). DAI is the injury most often responsible for coma and poor outcome following motor vehicle accidents (Grossman & Yousem, 1994). Although DAI can be first identified using electron microscopy within one hour of injury, delayed axotomy is common, with pathological changes not reaching their maximum until 24 to 72 hours post-injury (Bigler, 2001b).

While DAI is widespread in severe TBI, it is most often seen in the body and the splenium of the corpus callosum, and in the dorsolateral quadrant of the rostral part of the brain stem (Grossman & Yousem, 1994). The interface between gray and white matter is also particularly vulnerable to DAI, with the shearing forces associated with angular acceleration causing more damage to the grey matter because of its greater density (Adams, Doyle, Graham, Lawrence, & Mclellan, 1986; Halliday, 1999). The extent and location of DAI is of major significance in determining the outcome of individuals following TBI (Adams et al., 1991; Bigler, 2001a; Halliday, 1999). For example, lesions in the deep white matter have been found to be associated with more prolonged impairment of consciousness (Jenkins, Teasdale, Hadley, Macpherson, & Rowan, 1986).

In addition to the mechanical stretching and tearing effects of DAI, restrictions in the oxygen supply to the brain (hypoxic episode), caused by oedema and vascular damage, can lead to diffuse brain damage (Bigler, 2001b; Gale et al., 1999). Neuroimaging of TBI related hypoxic brain injury has revealed a pattern of diffuse damage characterised by reduced brain volume and ventricular dilation (Gale et al., 1999).

Although DAI and hypoxia have been identified as amongst the main causes of diffuse brain damage, Bigler (2001b) suggests that damage to the vascular system, along with complex biochemical changes associated with this damage, are often overlooked as part of the underlying pathology of diffuse brain damage. In addition, while a distinction has been made between focal and diffuse injuries, many TBIs involve a combination of both focal and diffuse damage (Halliday, 1999). However, diffuse brain injury is more difficult to detect using radiological scanning (Adams et al., 1991).

The diagnosis of focal and diffuse injuries in survivors of TBI is reliant upon various neuroimaging techniques and, in particular, computerised tomography (CT) and magnetic resonance imaging (MRI) (Adams et al., 1991; Katz, 1992). Blood clots (haematoma), along with regional and generalised volume loss, are amongst the most common sequelae of TBI that are identified by the CT scan (Kesler, Adams, & Bigler, 2000). Damage to the frontal and temporal lobes is frequently detected by CT scans following TBI (Groswasser, Reider-Grosswaser, Soroker, & Machtey, 1987; Reider-Groswasser et al., 2002). The enlargement of the temporal horn is thought to be an indicator of hippocampal atrophy, which has been shown to be correlated with cognitive impairment (Gale, Johnson, Bigler, & Blatter, 1994; Killiany et al., 1993). Enlargement of cerebro-spinal fluid (CSF) spaces, cerebral ventricles and subarachnoid spaces are also key features of TBI that are detected by the CT scan (Levin, Myers, Grossman, & Sarwar, 1981; Reider-Groswasser et al., 2002).

While the CT scan has been the most widely used neuroimaging technique following TBI, it does not detect all cases of brain damage. For example, Snoek, Jennett, Adams, Graham and Doyle (1979) found that 38 % of their severe TBI patients had normal CT scans. In addition, of the 19 patients in this study who died as a result of a TBI, five had normal CT scans (Snoek et al., 1979). Although being particularly effective in detecting acute haemorrhages, CT scans are often not able to detect diffuse damage caused by high velocity accidents, particularly if bleeding has not occurred (Wilson, 1990a). Thus, other methods of imaging, such as MRI scans, are needed in order to detect such damage.

The superiority of MRI, over CT, in detecting intracranial lesions and DAI has been demonstrated in a number of studies (Mittl et al., 1994; Snow, Zimmermann, Gandy, & Beck, 1986; Yokota, Kurokawa, Otsuka, Kobayashi, & Nakazawa, 1991). Even in very mild TBI, MRI has been able to detect DAI in approximately 30% of patients (Mittl et al., 1994). The majority of lesions identified by MRI following TBI have been found to be to be in the frontal and temporal lobes (Levin et al., 1987). One advantage of MRI is that it allows very precise quantification of callosum size (Verger et al, 2001). This is particularly important given that lesions to the corpus callosum are common following TBI (Adams, Graham, Scott, Parker, & Doyle, 1980; Gentry, Gedersky & Thompson, 1988). Magnetic resonance imaging studies have also revealed that the reduction in corpus callosum size following TBI can also be the result of neuronal loss in both hemispheres (Verger et al., 2001). Corpus callosum damage, as detected by MRI, has been found to be associated with several signs of interhemispheric disconnection, as indicated by the performance of TBI sufferers on dichotic listening and tachistoscopic identification tasks (Benavidez et al., 1999). Magnetic resonance imaging scans also have the advantage of being able to display small contusions that are undetectable, or masked by bony artefact, on CT scans (Katz, 1992). Furthermore, a large percentage of TBI patients whose CT scans are negative, display positive findings on MRI (Jones et al., 1998). However, while MRI is more sensitive than CT, there are some injuries that are not detected by either technique (Jones et al., 1998; Wilson, 1990a).

Although not widely used in clinical practice, there are a number of more recently developed neuroimaging techniques that can provide more detailed images of the brain than CT and MRI scans. While conventional MRI provides images of brain anatomy, functional MRI (fMRI) provides in vivo images of brain function, as changes in blood oxygenation within various brain regions are monitored in response to different stimuli (Chong, Sanders, & Jones, 1999). The ability of fMRI to detect differences between moderate to severe TBI and control participants was demonstrated in a study by Ricker, Hillary, & DeLuca (2001). MRI imaging was carried out while participants were administered a test of working memory and speed of information processing. The TBI participants displayed greater activation in the right hemisphere relative to controls, in addition to a more widespread dispersion of cortical activation (Ricker et al., 2001). It was as if TBI participants needed to recruit more cerebral resources than controls to complete the same working memory task (Ricker et al., 2001). Differences in cerebral activation patterns between TBI participants and healthy controls, whilst completing a working memory task, were also reported by McAllister et al., (1999). The ability of fMRI to produce images of different cerebral activation patterns in response to various task requirements has been described by Chong et al. (1999) as ‘watching the brain think’.

Positron Emission Tomography (PET), like the CT, provides a cross-sectional image of the brain. However, unlike the CT scan, it is also capable of providing dynamic information on a range of cerebral functions, such as local cerebral blood flow, regional metabolic rates for glucose and oxygen, as well as blood volume (Walsh, 1994). Langfitt et al. (1987) found that PET was capable of detecting regions of brain dysfunction, evidenced by decreased glucose metabolism, that were not visualised by CT or MRI scans. However, because of the cost of installation and operational complexity, the use of PET has been restricted (Walsh & O'Mara, 1994).

An alternative to the use of PET has been single proton emission computerised tomography (SPECT). This technique involves the use of a gamma camera to detect the differential uptake of a radio-active tracer by normal and pathological tissue. The most common sites of damage detected by SPECT following mild to moderate TBI tend to be within the temporal lobes, frontal lobes, and basal ganglia (Voller, Auff, Schnider & Aichner, 2001). A study of 24 TBI patients by Wiedmann et al., (1989) found that SPECT and MRI scans revealed abnormalities in a similar number of locations. However, less than half of these locations coincided, suggesting that both techniques revealed abnormalities not detected by the other (Wiedmann et al., 1989).

Finally, one of the more recently developed neuroimaging techniques is that of magnetoencephalography (MEG). This technique is able to detect variations in magnetic field potentials as a result of a range of pathological states (Lewine, Davis, Sloan, Kodituwakku, & Orrison, 1999). Using MEG to assess a group of mild TBI patients, Gaetz and Bernstein (2001) found that MEG detected abnormal activity in 45% of their patients. In contrast, MRI was only able to detect abnormal changes in 20% of these same patients.

Bigler (2001) has suggested that compared to MEG, MRI technology may only display the "tip-of-the-iceberg" with regard to underlying pathology. In addition, Bigler (2000) has also demonstrated the ability of MEG to detect more extensive pathology than both MRI and SPECT combined. While the superior sensitivity of MEG compared to other imaging techniques (i.e. MRI, SPECT) has been demonstrated, the combined use of MEG and MRI has been found to be more sensitive to detecting pathology than MEG alone (Lewine et al., 1999). Unfortunately, due to the relatively high cost of MEG and its specialised housing requirements, its use is still quite limited (Gaetz & Bernstein, 2001).

The difficulties associated with relying upon only one imaging technique following TBI have been highlighted by a number of studies, with abnormalities detected by one particular technique not detected by another (Jones et al., 1998; Kesler et al., 2000; Wiedmann et al., 1989). It is therefore important that multiple imaging techniques be used in the assessment of TBI (Kesler et al., 2000). In addition, Bigler (2001b) points out that, despite major advances in the development of brain-imaging procedures, there are inherent limitations in the ability of these techniques to predict behavioural outcome following TBI. In particular, caution should be exercised when relating abnormalities detected by CT scans soon after injury to neuropsychological outcome, as patients with similar initial damage may vary significantly in terms of the resolution of this damage. The complexities of human behaviour following TBI can best be understood by combining neuroimaging data with neuropsychological assessment (Bigler, 2001b).

1.6 Sequelae to Severe TBI

The sequelae to severe TBI varies widely. While individuals who have suffered a severe TBI experience physical, cognitive and psychosocial problems as a result of their injury, physical complaints dominate in the early stages post-injury (McKinlay et al., 1981; McLean, Dikmen,

& Temkin, 1993). These physical complaints often involve motor impairments resulting from an injury to the brain, rather than orthopaedic trauma. Although there are significant improvements in all areas of functioning in the weeks and months following a severe TBI, physical problems show the most rapid improvement in the first six months after injury (McLean et al., 1993). Beyond 12 months post-injury, it is the cognitive and psychosocial difficulties that predominate (McLean et al., 1993). It is now generally agreed within the literature that that the most disabling consequences of severe TBI are not the physical or neurological sequelae, per se, but rather impairments in cognition, emotions, and behaviour (Hendryx, 1989; McLean et al., 1993; Zasler, 1999). The following sections review the most common sequelae of severe TBI; namely disturbances in physical, communicative, cognitive, emotional, and behavioural function. Vocational outcomes following severe TBI are also discussed.

1.6.1 Physical Deficits

Motor and sensory deficits are both common following severe TBI, with the nature and extent of these deficits being dependent upon the severity and location of the injury. Motor deficits can take the form of a weakness or paralysis of one or both sides of the body, reduced coordination of muscle movements (ataxia), impaired balance, and reduced physical endurance (Ponsford, 1995). Visual disturbances are particularly common following TBI and include problems with visual acuity, visual field loss, an aversion to bright light (photophobia), and oculomotor disorders (Gronwall, 1991). In addition, alterations to the sense of smell (anosmia) are experienced by 20% to 30% of TBI sufferers (Costanzo & Zasler, 1992), and are often associated with bruising of the frontal lobes (Varney & Menefee, 1993) or damage to the limbic components of the temporal lobes (Martzke, Swan, & Varney, 1991). Despite these wide ranging physical difficulties, it appears that motor deficits do not cause the same level of distress to patients and their families as do the personality, temperament, and emotional changes caused by TBI (Hendryx, 1989).

1.6.2 Communication Deficits

Problems with communication can also occur following TBI, resulting from either a reduced capacity to articulate speech sounds (dysarthria) or an impaired programming of muscle movements to produce these sounds (dyspraxia) (Ponsford, 1995). Dysarthria, has been found to be one of the most persistent sequelae of severe TBI (Najenson, Sazbon, Fiselzon, Becker, & Schechter, 1978; Zasler, 1999). These speech impairments can significantly compromise the individual's return to work, as well as their social and recreational pursuits (Murdoch, 1996). Word finding (anomia) is also a common problem, as is mis-naming (Heilma, Safran, & Geschwind, 1971; Levin & Eisenberg, 1979; Levin, Grossman, Rose, & Teasdale, 1979; Murdoch, 1990). Communication difficulties can also arise out of impaired pragmatics, which refers to "*... the knowledge and activities of socially appropriate communication, which takes in much of the nonverbal aspects of communication, such as gestures, loudness of speech, etc., as well as verbal appropriateness*" (Lezak, 1995; p. 187). While most people who have sustained a TBI will recover basic language skills by the end of the first year post-injury, many will continue to display receptive and expressive language deficits (Groher, 1990).

1.6.3 Cognitive Deficits

The pervasive nature of the cognitive deficits associated with severe TBI has been well documented within the literature (Brooks, 1984; Levin, et al., 1979; Newcombe, 1982; Richardson, 1990; Thomsen, 1977). Of particular note are deficits in attention and memory function (Baddeley, Harris, Sunderland, Watts, & Wilson, 1987; Gronwall, 1987; McDowell, Whyte, & D'Esposito, 1997; Schmitter-Edgecombe & Wright, 2004; Zec et al., 2001;

Zoccolotti et al., 2000). This section reviews the literature regarding cognitive deficits following severe TBI. However, as attention and memory difficulties following severe TBI are the focus of subsequent chapters, these cognitive functions will only be briefly reviewed here.

Difficulties with attention are frequently reported following TBI (Whyte, Hart, Laborde, & Rosenthal, 1998). In everyday life, these difficulties include a tendency to be easily distracted (focussed attention) and to experience problems in attending to more than one thing at a time (divided attention). Difficulties with staying on-task over an extended period of time (sustained attention) have also been reported (Cicerone, 1996; Loken, Thornton, Otto, & Long, 1995). While TBI sufferers and their families consistently report difficulties with attention, research efforts to more clearly define these deficits have produced inconsistent results. In addition, where deficits amongst TBI sufferers have been found, some researchers have suggested that these deficits can be attributed to a reduced speed of information processing (Felmingham, Baguley, & Green, 2004; Ponsford & Kinsella, 1992; Whyte, 1996; Spikman et al., 1996). This issue is discussed in more detail in Chapter 2 and Chapter 4, which focus upon the assessment of attentional function following severe TBI.

Along with attentional problems, memory impairments are one of the most frequently reported and characteristic sequelae to TBI (Brooks, 1976; Gronwall & Wrightson, 1981; Dikmen, Temkin, McLean, Wyler, & McLean, 1987; Larsson & Ronnberg, 1987; Sunderland, Harris, & Gleave, 1984; Zec et al., 2001). Studies investigating the nature of memory deficits following severe TBI have identified a number of different forms of memory impairment, in particular impairments in working memory (Baddeley, Harris, Sunderland, Watts, & Wilson, 1987; Kinsella et al., 1996; Levin, 1990; Shum, Valentine, & Cutmore, 1999). A detailed discussion of the memory deficits caused by severe TBI is provided in Chapter 6, which focuses upon the relationship between attention and memory function following severe TBI.

Visual, visuoperceptual, and visuospatial disorders are also reported to occur following severe TBI (Geldmacher & Hills, 1997; Shum, McFarland & Bain, 1990; Zolton, 1990). For example, deficits in visual scanning have been found to make a major contribution to problems with visual attention following severe TBI (Shum et al., 1990). Visuoperceptual disorders following TBI have included problems with body schema and disorders of visual discrimination (Zoltan, 1990). In addition, visuospatial skills, such as form perception/constancy, depth perception, topographic orientation, figure-ground perception, and position in space, have been found to be compromised following severe TBI (Zoltan, 1990). Moreover, significant correlations have been found between the presence of these deficits and functional outcome (Sivak, Olson, Kewman, Won, & Henson, 1981).

Deficits in executive functioning are common following severe TBI and result in significant disability (Crosson et al., 1989; Fryer & Hafey, 1987; Stuss, 1991; Vogenthaler, 1987). These deficits include an inability to form or shift mental set, to be self directing and self initiating, to use feedback, knowledge or verbal mediation to regulate behaviour, and to plan and organise future activities (Stuss & Benson, 1986; Mattson & Levin, 1990). Deficits in executive function are often characterised by concrete thinking or, in other words, an inability to think abstractly (Scherzer, Charbonneau, Solomon, & Lepore, 1993). A reduced ability to abstract also impairs an individual's ability to reason and solve problems, which ultimately impacts upon the level of psychosocial functioning that can be achieved post-injury (Scherzer et al. 1993). Unfortunately, executive deficits are often not able to be detected by many structured standardised cognitive tests (Damasio, 1985). However, it has been estimated that executive deficits account for up to 90% of the failure rate of vocational rehabilitation programs amongst severe TBI sufferers (Corthell & Tooman, 1985).

1.6.4 Emotional Disturbances

Depression, anxiety, and post-traumatic stress disorder are amongst the most common emotional disturbances in individuals who have sustained a severe TBI. Using self-report measures, Tyerman and Humphry (1984) found that 60% of their 25 severe TBI patients were clinically depressed and 44% were clinically anxious. Bond (1984) found that depression in TBI was common and was related to the individual's growing awareness of their level of physical, cognitive, and social disability, and the impact of this disability upon their future prospects and life goals. Similar findings of a relationship between depression in severe TBI sufferers and an increased awareness of disability and the implications of these disabilities for their day to day lives, has been reported in a number of other studies (Fordyce, Roueche, & Prigatano, 1983; Godfrey, Partridge, & Knight, 1993). Ownsworth and Oei (1998) have identified a number of factors that may result in individuals with severe TBI being more susceptible to depression. These include a pre-existing psychiatric disturbance, damage to the anterior region of the brain, and the experience of significant failure when attempting pre-injury roles (Ownsworth & Oei, 1998). In addition, the lack of a close confiding relationship was found to be a predictor of emotional disorder and an indicator of those individuals who may be at risk of suicide (Kinsella et al., 1988). Risk of suicide has also been found to increase with time since injury (Yudofsky & Hales, 1992).

The presence of Post-Traumatic Stress Disorder (PTSD) has also been investigated following TBI (e.g. Alves, Colohan, Rimel & Jane, 1986; Hickling, Gillen, Blanchard, Buckley, & Taylor, 1998; Stevens, 1982). Hickling et al. (1998), in a study of 107 participants who had lost consciousness as a result of a motor vehicle accident, found that 40 % of these participants met the diagnostic criteria for PTSD, despite having little or no recall of the accident. Stevens (1982) noted that PTSD tended to develop when the TBI sufferer was reaching the peak of their recovery potential and awareness of their disability. In addition, the likelihood of PTSD developing after TBI has been found to be dependent upon a number of pre-morbid issues, including the existence of certain personality traits such as instability and feelings of inadequacy (Lishman, 1978; Stevens, 1982).

1.6.5 Behavioural Disturbances

Behavioural disturbances are frequently reported following severe TBI (Bond, 1984; Lishman, 1978; Pachet, Friesen, Winkelaar, & Gray, 2003; Thomsen, 1974). These disturbances can range from severe acts of aggression of a sudden, unprovoked, primitive and poorly organised nature (e.g. flailing about, spitting, scratching), to a pattern of behaviour which resembles that of non-TBI individuals who have been characterised as having a 'short fuse' (Miller, 1990). It has been suggested that the more severe and sudden acts of aggression may be related to seizure activity within the medial portion of the temporal lobes (Lishman, 1978), which contain the limbic system structures that are implicated in the regulation of emotion and motivation (Wood, 1987).

Younger TBI sufferers have been found to display more severe behavioural disturbances than older individuals, with younger individuals displaying greater levels of irritability, emotional lability, emotional blunting, aggressiveness, and a lack of sexual inhibition (Thomsen, 1989). A number of studies have found that, while TBI patients were often not aware of changes in their personality, temperament or behaviour, these were the very changes that caused most concern for their families (Hendryx, 1989; Jacobs, 1990; Lezak, 1978). Decreased behavioural regulation prevents individuals with severe TBI from returning to their previous lifestyle, resulting in social isolation, loneliness, and sexual frustration (Strauss & Finegan, 1990).

1.6.6 Vocational Outcomes

There have been a significant number of research investigations that have documented the poor vocational outcomes of individuals who have suffered a severe TBI (Ben-Yishay, Silver, Piasetsky, & Rattock, 1987; Brooks, McKinlay, Symington, Beattie, & Campsie, 1987; Jacobs, 1987; McMordie, Barker & Paolo, 1990; Oppermann, 2004). Studies such as these have consistently found that even where vocational rehabilitation services are provided, unemployment rates remain in the 50% to 80% range following severe TBI (Wehman, Kregel, & Sherron, 1993). In addition, job 'turnover' rates tend to be high and wages are greatly reduced from pre-morbid levels (Wehman et al., 1993). Vocational outcome is particularly important given that many TBI sufferers are still relatively young and, as a result, are at risk of losing many potentially productive years (Wehman et al., 1993). Moreover, the loss of income puts immense strain upon their family who, in many cases, were dependent upon the TBI sufferer as the major provider of the family income (Dikmen, Machamer & Temkin, 1993; Wehman et al., 1993). As a result of these economic factors, and the link between vocational status and self-esteem, vocational status has become one of the most important measures of outcome in TBI research (Kreutzer, Wehman, Morton et al., 1988). In fact,

> "*vocational rehabilitation has been referred to as the final frontier that the head injured adult must cross if comprehensive rehabilitation services are to be judged successful*" (Ryan, Sautter, Capps, Meneese, & Barth, 1992, p. 175).

1.7 Summary and Conclusions

Traumatic brain injury has been identified as a major public health problem (Farmer, 2000). Epidemiological studies reveal that 320 to 400 per 100,000 South Australians suffer a TBI each year, a figure which is slightly higher than the incidence rates reported in comparable studies in the US and Europe (Hillier et al., 1997). Although only 10% of TBIs are classified as severe, the challenges faced by rehabilitation professionals in addressing the cognitive and behavioural sequelae of severe TBI far outweighs that of the mild and moderate TBI groups (Parker, 1990). As a result it was decided to focus specifically upon severe TBI sufferers within this thesis.

Damage to the frontal and temporal lobes, in addition to DAI, have been found to be characteristic features of severe TBI. While improved neuroradiological techniques are better able to identity the nature of this damage following severe TBI, it is suggested that the deficits following TBI can best be understood by combining neuroimaging data with neuropsychological assessment (Bigler, 2001b).

While the physical and communication deficits resulting from severe TBI can present some barriers to an individual's return to their previous family, social, and vocational life, it is the behavioural and cognitive deficits that are likely to pose the most significant obstacles (McLean et al., 1993; Zasler, 1999). Attention and memory impairments, in particular, are the most frequently reported cognitive deficits following severe TBI (Bond, 1975). However, while TBI sufferers and their families consistently report difficulties with attention, neuropsychological studies have produced inconsistent results. There is therefore a need to investigate further the nature, assessment, and recovery of attentional function following severe TBI. The following chapter commences such an investigation by reviewing the development of attentional theories and models. The literature on attentional function following severe TBI is also examined in this chapter. This review leads to the development of number of aims that form the experimental basis for the remainder of this thesis.

CHAPTER 2

ATTENTION

2.1 Introduction

Attention is a term that is commonly used in everyday life. However, within the experimental and clinical literature, there has been considerable debate regarding the definition and theoretical underpinnings of attention, and the means by which it should be assessed. While attention was once regarded as a relatively unitary process by some early authors (e.g. Broadbent, 1958), more recently it has been recognised that attention is comprised of a number of interrelated components or processes (Nissen, 1986; Walsh & O'Mara, 1994). The identification of these attentional components has resulted in a more coherent approach to the study of attention and the development of attentional models.

The current chapter begins by providing a brief historical review of the early theories of attention. Difficulties associated with attempts to define attention are also discussed. The key attentional components of *arousal*, *orienting*, *hemi-attention*, *focussed attention*, *divided attention*, *sustained attention*, and *supervisory attentional control* are identified, as are their neuroanatomical substrates. While the review of the literature revealed a range of theoretical views and models of attention, it was apparent that within recent years there has been a significant degree of convergence in support of one particular model of attention; namely the model proposed by Posner and colleagues (Posner & Petersen, 1990). Furthermore this model seeks to explain the relationship between the various components of attention and their neuroanatomical substrates. The chapter concludes by examining disorders of attention following TBI and outlining the general aims of this thesis.

Attentional disorders associated with a number of diagnostic groups are also reviewed and, in particular, attentional problems associated with severe TBI. The chapter concludes by outlining the general aims of this thesis.

2.2 An Historical Perspective of the Study of Attention

Attention emerged as a central topic within psychology during the late 1800s and early 1900s. Amongst the earliest authors who attempted to define attention was James (1890) who stated:

> *"Everyone knows what attention is. It is the taking possession of the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration or consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others ..."*
>
> *(James, 1890, p. 403-404).*

Although the definition proposed by James (1890) encompassed a range of attentional processes, these processes were described in quite global terms and, as such, were difficult to operationalise. One of the first attempts to more clearly describe these attentional processes was carried out by Titchener (1908), who proposed an attentional model based upon the existence of a dual component system. At one level, this system involved a process that increased the clarity of the sensations or ideas that were attended to and, at a second level, incorporated a process to inhibit other stimuli or memory images (Titchener, 1908). The view that attention was central to all cognitive and behavioural processes is reflected in Titchener's (1908) description of attention as being "... the nerve of the whole psychological system" (p. 173).

While the study of attention flourished in the early part of the 20th century, providing the foundation for many of the attentional theories that are used today, the rise of the Behaviourist and Gestalt movements in the 1920s through to the 1950s saw the study of attention effectively banished from scientific psychology (Kahneman, 1973). It is suggested by Kahneman (1973) that this demise of attention in scientific research was due to the fact that the concept of attention could not be explained by a clear set of stimulus–response rules. In the period following World War II, however, there was a strong revival of interest in attention. This revival was largely prompted by the need to investigate human performance when operating increasingly sophisticated technological equipment (Naatanen, 1992). Studies of the performance of radar equipment operators, for example, found surprising limitations in the ability of individuals to process simultaneously presented information (Kahneman & Triesman, 1984).

2.2.1 Early Theories and Models of Attention

Early attentional theories and models were based upon experimental studies that examined selective attention using dichotic listening paradigms (e.g. Cherry, 1953; Moray, 1959; Treisman, 1964). Participants typically wore stereo headphones, with a different message being played to each ear. Most of these experiments instructed the participants to attend to only one ear and repeat aloud (shadow) the message as soon as possible after hearing it (Cherry, 1953; Treisman, 1960, 1964). Using a dichotic listening procedure, Cherry (1953) found that participants were able to successfully shadow the *attended* message. When questioned about the *unattended* message, participants were able to accurately report on the essential physical features of the message, such as whether it had been a man's or woman's voice. However, they seemed to have little knowledge of the meaning of the message (Cherry, 1953), as evidenced by the fact that they were unaware when the voice to the *unattended* ear changed from English to German, or when it was played backwards (Treisman, 1964). These dichotic listening studies highlighted the limitations upon individuals to process multiple channels of information concurrently. It has been suggested that these limitations result in the initial suppression or queuing of stimuli, which are processed later (Kahneman, 1973). The apparent queuing of stimuli is evidenced in everyday life by the 'double take' experience; for example, when one returns to a stimulus that was initially ignored or not fully processed (Kahneman, 1973). A number of theories and models of selective attention have used the image of a bottleneck to conceptualize this limitation on processing multiple channels of information (e.g. Broadbent, 1958; Deutsch & Deutsch, 1963). However, there is a lack of agreement amongst authors as to the location of this bottleneck (Kahneman, 1973). While some theories suggest that the bottleneck occurs early on in the processing chain (e.g. Broadbent, 1958), before any semantic analysis has taken place, others argue that it occurs at a later stage, subsequent to semantic analysis (e.g. Deutsch & Deutsch, 1963). As a result, these bottleneck theories can be broadly categorised as either *early* or *late* selection theories.

2.2.1.1 Early Selection Filter Theories

In an attempt to explain the findings reported in the dichotic listening studies of Cherry (1953), Broadbent (1958) devised a model of attention that was, perhaps, the most prominent and influential of the early selection theories. This two-stage model, which is depicted in Figure 2.1, proposes that all stimuli are received in parallel and are briefly held in a sensory store (S-system). This sensory store carries out a number of automatic parallel analyses of the elementary physical properties of all the stimuli (e.g. pitch, intensity, spatial location, symmetry, colour). A large amount of incoming information can be stored in this sensory store (Best, 1986) but it can only be held briefly as an echo or image that has not been fully analysed (Kahneman, 1973). The second stage of this model involves the selective filtering of a subset of the information in the sensory store and the transfer of this selected information into the limited capacity processing system (P-system). The filter selects items based upon common characteristics or features and rejects all others (Broadbent, 1958; Kahneman, 1973).

It is at this point that the bottleneck occurs, as this limited capacity processing system operates in a serial rather than a parallel mode. Stimuli reaching the filter includes both external stimuli and information retrieved from long term memory (refer to Figure 2.1). Once the perceptual analysis of the first stimuli has been completed, and a response (R) initiated, the filter allows a new stimulus to enter from amongst the *echos* and *images* in the sensory store (S-system) (Kahneman, 1973). Information that does not pass through the filter receives no further analysis and is subject to quite rapid decay.

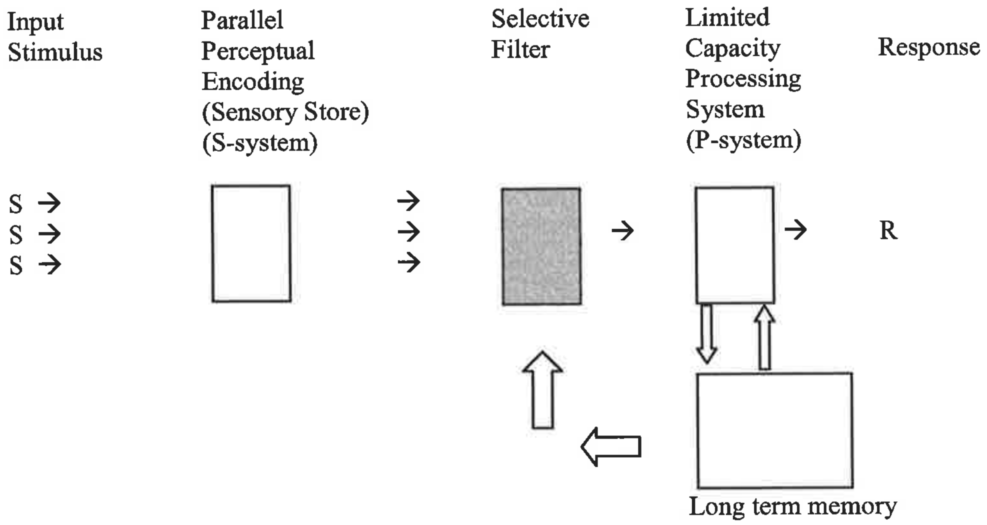


FIGURE 2.1 Broadbent's (1958) filter model (adapted from Treisman, 1964 and van Zomeren & Brouwer, 1994).

This early model of Broadbent (1958) assumed that whatever information did not pass through the filter was disregarded. However, subsequent studies have revealed that there is semantic processing of supposedly unattended information. For example, using a dichotic listening task, it was found that participants sometimes responded to their name on an 'unattended' channel (Moray, 1959) and occasionally responded to the meaning of words on that channel (Treisman, 1960). According to the Broadbent (1958) model, this information should have been discarded (Naatanen, 1992). However, it appears that stimuli were able to 'break-through' the filter and draw upon more elaborate processing. This break-through of information is illustrated in everyday life by the cocktail party effect, whereby an individual can listen to a particular conversation in a party situation, apparently oblivious to all of the other conversations within the room (Cherry, 1953). However, he/she is still able to detect important information that is mentioned in another conversation within hearing range (e.g. one's own name).

In response to studies that revealed a 'breakthrough' of the unattended information into semantic processing, Treisman (1964) suggested that information was not, in fact, disregarded but rather that it was reduced or attenuated and processed, albeit in a more superficial way. However, this attenuated information was still sufficient to activate highly primed semantically related 'units' of information in a 'mental dictionary' within long term memory (Treisman, 1960). Each of these units is thought to have a threshold which must be reached for perception to occur (Kahneman, 1973). The threshold for a unit of a highly significant nature (e.g. one's own name) is permanently lowered, while the threshold for a unit related to the context of the situation is lowered temporarily (Kahneman, 1973). Such a theory explains the ease with which hearing one's own name, or important personal information, 'breaks-through' into an attended channel. Unlike Broadbent's (1958) filter theory, the filter in Treisman's (1964) attenuation theory is not an all-or-none phenomena; non selected channels are not completely shut off but rather turned down or dampened (Best, 1986). This model, according to van Zomeren and Brouwer (1994),

> *"... is a biologically sensible mechanism as it enables animals and humans to react to signals heralding danger even when they are fully concentrated on a task*" (p. 14).

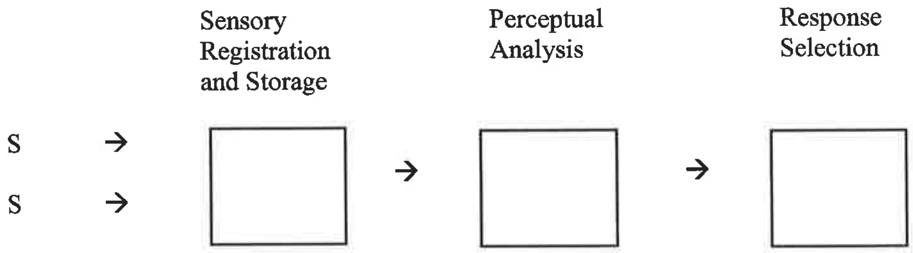
2.2.1.2 Late Selection Filter Theories

One of the main criticisms of Treisman's attenuation theory, however, is that the preselection analysis is almost as complete as the attentive analysis (Best, 1986). A simpler late selection alternative was therefore proposed by Deutsch and Deutsch (1963), who challenged previous ideas by stating that

> *"... a message will reach the same perceptual and discriminatory mechanisms whether attention is paid to it or not"* (p. 83).

Deutsch and Deutsch (1963) proposed that all incoming stimuli are analysed for importance, with the more important information receiving more detailed analysis. According to late selection theories, the bottleneck is located at or just prior to the stage of response selection. A comparison of simplified versions of the early and late selection theories is outlined in Figure 2.2. As can be seen, whereas the early selection model involves selection prior to perceptual analysis, the late selection model involves perceptual analysis of all stimulus information, with selection occurring at the point of response selection. Unfortunately, the late selection model of Deutsch and Deutsch does not clearly specify how importance is assigned to a particular stimulus (O'Donnell & Cohen, 1993). In addition, Treisman (1964) has been critical of this model, highlighting the enormous demands that would be placed upon an information processing system by having to arrange all stimuli in terms of order of importance before selecting which stimuli receives more detailed analysis.

(a) Early Selection



(b) Late Selection

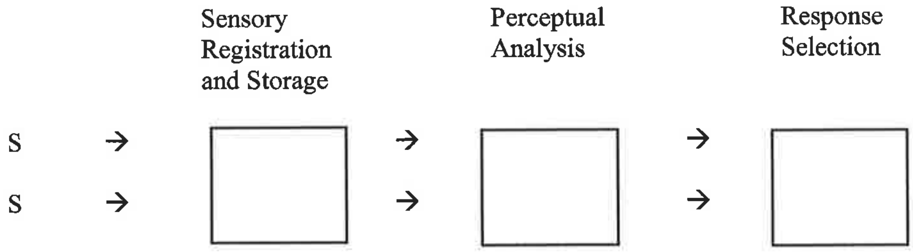


FIGURE 2.2 A comparison of simplified versions of early and late selection theories (adapted from Kahneman, 1973).

As an alternative, Norman (1968), who was another proponent of late selection models, suggested that all sensory information is transmitted in parallel to a memory storage system. This sensory information automatically activates an existing representation of this information within storage without any intervening cognitive processes. In this way, all sensory inputs can be analysed. However, this level of sensory analysis is not sufficient to guide the selection of inputs, as selection is based upon contextual, grammatical, and meaningful cues, as well as the physical form of the input (Norman, 1968). Thus, some measure of pertinence has to be carried out before the selection process can take place. While some forms of input will have permanently high levels of pertinence (e.g. one's own name), the pertinence of other forms of input may fluctuate depending upon the current situation and future expectations (Norman, 1968). In Figure 2.3, sensory inputs activate representations *a*, *b*, and *c* in storage. This sensory information has resulted in the pertinence input activation of items *c*, *d*, and *e* in storage. The output of the storage system is therefore a combination of the items activated by sensory inputs and those activated by pertinence inputs. Of note is the fact that item *c* has received both sensory and pertinence activation. It is at this next point where selection occurs, as those items which have the highest levels of activation (i.e. *c*) are selected for further processing (Norman, 1968). The remaining sensory information that is not judged as pertinent receives no further analyses and is subsequently forgotten (Best, 1986).

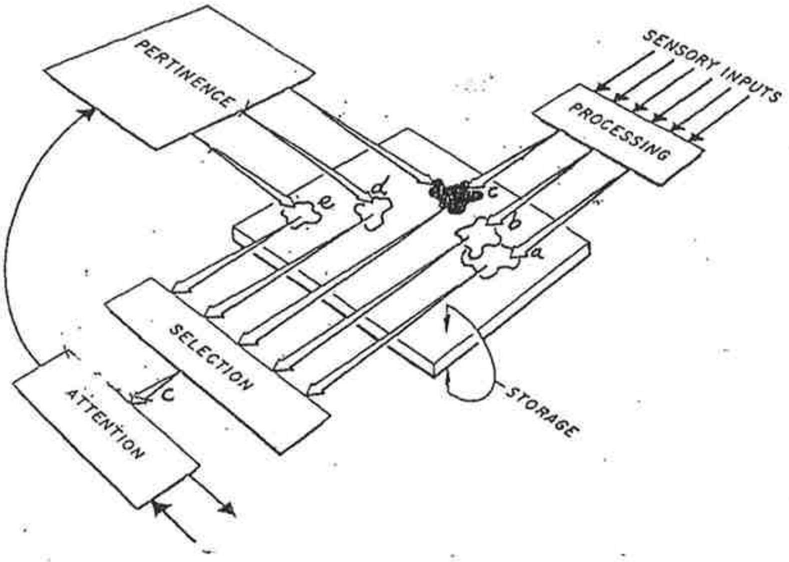


FIGURE 2.3 An outline of Norman's late selection model (adapted from Norman, 1968)

Both the Deutsch and Deutsch (1963) and Norman (1968) models have been criticised because of the lack of specificity in terms of how judgements regarding the value or importance of incoming stimuli are determined (Kahneman, 1973). However, one explanation of how such judgements may be made has been provided by Johnston and Heinz (1978), who argued that individuals can control the extent to which stimuli are processed by carrying out preliminary analyses of the material in working memory. There are basically two types of analyses involved, sensory and semantic, with sensory analysis being the first, and least effortful, level of assessment. Sensory analysis involves a relatively simple analysis of the physical properties of the stimulus (e.g. the pitch, loudness of a particular group of sounds), while semantic analysis involves an analysis of meaning. Thus, while sensory analysis may be able to identify a familiar speaker, it will require semantic analysis to determine the meaning of the message. However, where sensory analysis is able to sufficiently analyse the presenting information, it is not necessary for the information to progress to a semantic level of analysis, which is more resource dependent (Best, 1986). If the sensory analysis is not sufficient, higher level semantic analysis is entered into (Johnston & Heinz, 1978). Semantic analysis is much more effortful because more knowledge is required to carry it out (Best, 1986). Furthermore, if excessive working memory capacity is taken up with this semantic analysis, there is likely to be less spare capacity available for the analysis of any additional information (Johnston & Heinz, 1978).

While early studies of attention were dominated by theories that proposed a filter and bottleneck at some point in the selection process, it has been suggested more recently that such a selection process was unrealistically rigid, as filtering represented an all-or-none phenomena (O'Donnell & Cohen, 1993). There was also a need to explain how multiple-channel monitoring of stimuli occurs; in other words, how an individual is able to divide their attention. This division of attention is discussed in more detail in section 2.3.4.

There are therefore significant limitations associated with many of the early theories of attention. Many of these difficulties were attributed to the fact that there was no adequate definition of attention and its related components (Worden, 1966; Naatanen, 1992). The absence of such a definition has lead to significant conceptual confusion, particularly when making comparisons between studies. After briefly discussing some of the difficulties associated with defining attention, the following section identifies a number of components of attention and outlines a more recent model that underpins their operation.

2.2.2 Towards a Definition and Model of Attention

One of the major impediments to the study of attention within both the experimental and clinical literature has been the lack of a clear definition of attention and its associated components. Johnson and Dark (1986) commented upon what they perceived as an apparent widespread reluctance, within the literature, to define attention, pointing out that it is difficult to conceptualize a process that is not well defined and difficult to falsify empirically a vague conceptualization.

Worden (1966) suggested that the problems associated with defining attention arose because attention involved the operation of selective forces at all 'psychological levels', from sensory processes through to information processing and, finally, to response. This issue was also recognised by Eysenck and Keane (1990) who suggested that there is a danger that a concept that is used to explain everything will turn out to explain nothing. Similarly, Allport (1993) stated that there could not be a simple unitary theory of attention "*...any more than there can be a simple theory of thought*" (p. 206). However, Cohen et al. (1993) have suggested that the fact that attention could not be reduced to a single neurobehavioural event should not preclude it from consideration as an important construct to be investigated.

The last two decades have seen researchers acknowledge the difficulties associated with providing a 'global' definition of attention (van Zomeren & Brouwer, 1992). Coupled with this acknowledgement is the finding that attentional functioning results from the coordinated action of several interrelated components or elements of attention (Chan, 2001; Cohen, Sparling-Cohen, & O'Donnell, 1993). As a result, there has been a move away from attempting to provide a single global definition of attention, in favour of providing more operational definitions for these individual components.

2.3 Components of Attention

Within psychology, the two key approaches that have been used to investigate attentional function have been the psychometric and experimental methods. Psychometric methods have typically involved the identification and interpretation of patterns of relationships between neuropsychological tests using correlational methods (Strauss, Thompson, Adams, Redline, & Burant, 2000). Factor analytical studies have formed the basis of this approach. In contrast, the experimental method has studied the effects of experimental manipulations of specific attentional functions using relatively simple information processing tasks (Strauss et al., 2000). While many of the early studies of attention produced little agreement with regard to a model of attention or its components, more recent studies, using both neuropsychological and experimental techniques have produced a significant consensus with regard to the components of attention (Leon-Carrion et al., 1996; Posner & Petersen, 1990). The following section describes and defines each of these components; namely *arousal*, *hemi-attention*, *orienting*, *selective attention*, *sustained attention*, and *supervisory attentional control.* The interrelated nature of the components is then discussed, as are their neuroanatomical substrates.

2.3.1 Arousal

Arousal is the basic biological component which affects general receptivity to all stimulation and, as a result, variations in the level of arousal have significant implications for attentional function (van Zomeren & Brouwer, 1994). For example, it becomes more difficult for an individual to attend to a stimulus if they are under- or over-aroused (Vanderploeg, 2000). The terms 'arousal' and 'alertness' are often used interchangeably within the literature to describe an individual's general receptivity to stimulation (Posner, 1975). In the healthy individual, alertness can range from relatively low levels during sleep, to the elevated levels that are required in order to carry out complex cognitive or physical tasks. In contrast, within neuropsychological settings, a patient's level of alertness can vary from a deep coma and its various stages, through to levels that are characteristic of healthy individuals. Arousal is therefore a fundamental component of attention.

Changes in arousal or alertness are typically defined as either *phasic* or *tonic*. *Phasic* changes in alertness occur as a result of changes in the level of stimulation within the individual's environment (Posner & Rafal, 1987). For example, there will be a sudden increase in arousal following a warning signal which the individual knows will require a quick response (Posner & Rafal, 1987). In contrast, *tonic* changes occur more slowly and determine how awake an individual is from one time of the day to another (van Zomeren & Brouwer, 1994). *Tonic* changes are determined by physiological changes within the individual, such as the gradual changes in deep body temperature which occur over a 24 hour period (van Zomeren & Brouwer, 1994).

2.3.2 Hemi-attention

The study of hemi-attention has been given a high profile within the literature (Geschwind, 1982), particularly the study of unilateral disorders of attention (hemi-inattention). Hemi-inattention or neglect are terms that describe an individual's lack of awareness or response to tactile, auditory, or visual stimuli that are presented to the side of the body contralateral to the lesion (Halligan & Robertson, 1992; Heilman et al., 1993). Examples of the behavioural manifestations of visuo-spatial neglect include shaving, dressing or grooming only one side of the body; failing to notice food on one side of the plate, and neglecting to fill in one side of a form (Halligan & Robertson, 1992). Even when using mental imagery, some individuals who suffer from visuo-spatial neglect may omit to report features on one side of their image (Meador, Loring, Bowers, & Heilman, 1987). In addition, the independence of visual neglect from disorders of vision has been demonstrated by a number of authors (Bradshaw, Nettleton, & Pierson, Wilson, & Nathan, 1987; Ladavas, 1987).

While right sided neglect has been reported following left hemisphere lesions (Albert, 1973; Gainotti, D'Erme, Monteleone, & Silveri, 1986), it tends to be less common and less severe than left sided neglect (Denes, Semeza, Stoppa, & Lis, 1982). Hemi-inattention (neglect) therefore has a significant impact upon an individual's ability to select all of the necessary information and material from their environment. As a result, the presence of hemi-inattention will significantly compromise all other components of visual attention.

2.3.3 Orienting

The orienting response was originally referred to by Pavlov (1927) who described it as the '*investigating*' or '*what is it reaction*' (Naatanen, 1992). However, it is only in relatively recent times that the orienting response has taken precedence within the development of attentional theories (e.g. Posner, 1980). Posner, Cohen and Rafal (1982) have suggested that *"perhaps the simplest of all cognitive acts involves the orienting of attention toward an event"* (p. 187).

The orienting of attention to different locations in the visual field has been likened to a spotlight that enhances the information highlighted by the beam (O'Donnell & Cohen, 1993). Studies investigating the orienting of attention have used simple stimuli in experimental settings, designed to minimize the influence on participant performance of memory and response generation (O'Donnell & Cohen, 1993). Most studies that have investigated the orienting of visual attention have used static visual displays (O'Donnell & Cohen, 1993). For example, Posner and colleagues have developed an experimental method that they have used to study the orienting of attention in both healthy and patient populations (Posner, 1980; Posner et al., 1982; 1984; 1987; Posner & Petersen, 1990). This experimental task, known as the Covert Orienting of Attention Task (COAT) has, according to Posner, been able to identify the fundamental mental operations underlying visual selective attention; namely the *disengaging*, *moving*, and *engaging* of visual attention (Posner, 1980; Posner et al., 1982; 1984; 1987). These mental operations, along with a description of the COAT, are discussed in detail in Chapter 3.

The administration of the COAT, in conjunction with neuroimaging studies, has also revealed the underlying neuroanatomical structures responsible for the orienting of attention. As a result, Posner and colleagues have proposed a model of attentional function that describes the relationship between these neuroanatomical structures and the operations involved in attentional orienting. This model will be discussed in more detail in Section 2.4 below, and a more detailed analysis of Posner's work will be provided in Chapter 3, as the COAT forms the basis of this chapter.

2.3.4 Selective Attention (Focused and Divided Attention)

Selective attention has been the most widely studied aspect of attention. As discussed previously, much of the earlier work on selective attention involved the development of theories that described selective attention in terms of a filter process. However, there was considerable disagreement regarding the stage of processing at which the filtering occurred (e.g. Broadbent, 1958; Deutsch & Deutsch, 1963; Norman, 1968; Treisman, 1964). More recently, selective attention has been conceptualised as consisting of two separate sub-components, namely focused and divided attention (Shiffrin & Schneider, 1977).

2.3.4.1 Focused Attention

Focused attention refers to the ability to attend to a subset of information while avoiding or inhibiting distraction from other irrelevant information (Simpson & Schmitter-Edgecombe, 2000; Sohlberg & Mateer, 1989). Many of the earlier experimental studies of focussed attention utilised the dichotic listening task (refer to p. 32). The extent to which the participant could focus their attention was measured by their ability to prevent the irrelevant stimuli from interfering with the primary task or message (Kahneman, 1973).

2.3.4.2 Divided Attention

Divided attention involves attending to more than one activity at a time (Park, Moscovitch & Robertson, 1999). In everyday life the need to divide attention is a common occurrence. It is on tasks of divided attention that the limited capacity of the human information processing system becomes most apparent (Ponsford & Kinsella, 1992; Schneider & Shiffrin, 1977). In fact, the ability to divide attention is dependent upon two key factors; (a) the mode of information processing, and (b) the capacity limitations of the human information processing system.

2.3.4.2.1 Modes of Processing (Automatic vs Controlled Processing)

Shiffrin and Schneider (1977) acknowledged that as tasks become overlearned they appear to be executed automatically and do not require conscious processing. As a result, they place minimal demands upon processing capacity. In addition, Shiffrin and Schneider (1977) postulated that automatic processing occurs in parallel and therefore its capacity for processing information is 'almost unlimited'. On the other hand, more complex (e.g. divided attention) and novel tasks draw heavily upon attentional resources, and are processed in a more controlled manner. In contrast to automatic processing, conscious controlled processing requires many more processing resources and, as such, is much more vulnerable to interference from other introduced tasks. As a result, it is thought that conscious controlled processing occurs in a serial manner (Shiffrin and Schneider, 1977). Processing in response to divided attention tasks is therefore carried out in a controlled serial manner.

2.3.4.2.2 Capacity Limitations

The total amount of attention that can be deployed by an individual at any one time is limited (Best, 1986). As a result, the ability to process and respond to simultaneous inputs depends primarily on the total demands of the activities amongst which attention is to be divided (Kahneman, 1973). If a stimulus is complex and requires controlled processing, a large number of resources are required (Kahneman, 1973). In situations where there are a number of complex stimuli, the total resource capacity may well be used up (Best, 1986). An additional stimulus would therefore not be processed and would go unnoticed (Best, 1986).

Evidence of the impact of task complexity on divided attention can be seen in the apparently mixed results from studies of the parallel processing of simultaneous inputs. While some studies reveal that such processing can occur with little interference between tasks of low complexity (e.g. Lindsay, 1970; Lindsay & Norman, 1969), others have found that it can occur but that its effectiveness is impaired when there is moderate task complexity (Ninio & Kahneman, 1974; Treisman, 1970: Treisman & Fearnley, 1971). In addition, there have been situations involving high task complexity where parallel processing has failed altogether (Kahneman, 1973). It has also been acknowledged that attentional capacity is not a fixed commodity and may vary in response to factors such as changes in arousal level (Kahneman, 1973).

> *"Lulled into a pleasant state of drowsiness by his teacher's voice, the schoolboy does not merely fail to pay attention to what the teacher says; he has less attention to pay"* (Kahneman, 1973, p. 3).

2.3.5 Sustained Attention

Sustained attention refers to the ability to maintain an effective and consistent behavioural response over an extended period of time (Sohlberg & Mateer, 1989; Weber, 1990). It is typically assessed by vigilance tasks in which the participant is required to detect specified targets that occur infrequently against a background of other irrelevant targets (Weber, 1990). The time duration over which such tasks should run was suggested by Mackie (1977) to be at least 20 minutes. However, a more conservative figure of at least five minutes has been suggested by Parasuraman and Davies (1984). Despite the sparsity of targets and minimal response output requirements of sustained attention tasks, participants will often report that these tasks require considerable effort (Pardo, Fox, & Raichle, 1991). In everyday life, deficits in sustained attention are characterized by an individual who can only remain 'on task' for short periods of time (i.e. seconds to minutes) or whose performance fluctuates dramatically during such a period (Sohlberg & Mateer, 1989).

Research interest in sustained attention grew out of the need to assess human performance across a number of tasks including the monitoring of radar screens and the operation of industrial equipment over extended periods of time (van Zomeren & Brouwer, 1994). It appears that sustained attention may draw upon both the automatic and controlled components of attentional function (Weber, 1990). Moreover, capacity considerations seem to play a more limited role in sustained compared to divided attention tasks (Weber, 1990).

2.3.6 Supervisory Attentional Control

The concept of a Supervisory Attentional Control System is relatively new to the study of attention (van Zomeren & Brouwer, 1994). Supervisory Attentional Control is a mechanism that deals with novel situations, and is activated when an individual is required to attend to multiple channels of information and when decisions have to be made regarding the allocation of attentional resources to tasks (Shallice & Burgess, 1993). While the notion of executive control of brain functions was originally introduced by Luria (1966), it was Shallice (1982; 1988) who developed the Supervisory Attentional Control system to account for the monitoring and regulation of attentional resources in a goal-directed manner. The Supervisory Attentional Control system involves the running of highly specialised programs, or schemas, in response to the specific attentional task at hand (Shallice, 1982; 1988).

The term 'schema' refers to an internal representation or way of thinking about certain situations and events (Johnston & Dark, 1986). Schemas provide a structured model of an individual's environment or experience (Baddeley, 1990). Applying a particular schema to a certain situation will assist the individual to process and understand the situation, as the schema encapsulates the individual's existing experience and knowledge of similar situations (Baddeley, 1990). Schemas can be activated by various related cues within the environment and can influence the way certain information is processed or disregarded. The role of the Supervisory Attentional Control system is to select the most appropriate schema when faced with a complex novel task (van Zomeren & Brouwer, 1994). In addition to the activation of schema for novel events, Shallice (1982) also discusses the process of contention scheduling. In contrast to the Supervisory Attentional Control system, contention scheduling deals only with routine and well learned tasks (Shallice & Burgess, 1993). Contention scheduling is an automatic conflict resolution process that selects one of the competing schemas on the basis of environmental cues (Shallice & Burgess, 1993). There will, however, be some occasions when the SAC suppresses the more automatic contention scheduling so that a non-routine aspect of the stimulus material can be focussed upon (van Zomeren & Brouwer, 1994).

There are certain similarities between the Shallice model of Supervisory Attentional Control and the model of working memory described by Baddeley (1966; 1993). Working memory, according to Baddeley, involves a process of holding information on line while some analysis or manipulation of this material is carried out. The working memory model contains three major components, including two slave systems, which are responsible for storing verbal and non-verbal information, and a central executive system (CES). In particular, there are similarities between the supervisory attentional control system and the central executive system within working memory, with both systems responsible for the regulation and allocation of attentional resources. In fact, Baddeley (1993) raised the question as to whether 'working memory' should become known as 'working attention'.

This section has therefore outlined a number of attentional components. There is now also considerable consensus within the literature regarding the interrelated nature of these attentional components (Kerns & Mateer, 1996). Importantly, Leon-Carrion et al. (1996) found that essentially the same attentional components could be identified using either psychometric or experimental measures. Developments in neuroimaging techniques have also enabled the neuroanatomical substrates of these attentional components to be identified. The relationship between these attentional components and their neuroanatomical substrates are discussed in the following section.

2.4 Neuroanatomical Substrates of Attention

For nearly 20 years after the introduction of Broadbent's filter theory of attention, little physiological evidence was available to identify a biological base for theories of attention (O'Donnell & Cohen, 1993). However, in recent years, advances in brain imaging techniques, particularly functional imaging techniques, have greatly increased the ability to identify the neuroanatomical correlates of attentional behaviour. Research studies have typically involved participants performing a standard psychometric or experimental task while undergoing a neuroimaging procedure. This research has enabled the relationship between the components of attention and their neuroanatomical substrates to be postulated. With respect to *arousal*, it has been found that the tonic component of arousal is controlled by the left hemisphere (Salazar et al., 1986), while phasic changes in arousal have been linked to the right hemisphere (van Zomeren & Brouwer, 1994). In addition, Stuss and Benson (1986) have identified a relationship between these attentional processes and specific neuroanatomical systems. Tonic changes in alertness have been found to be controlled by the anterior reticular activating system, with phasic changes being determined by the thalamic projection system, with its primary connections leading to the orbital frontal cortex (Stuss & Benson, 1986).

Neuroimaging studies have also revealed a relationship between *hemi-attention* (i.e unilateral neglect) and specific cortical sites. While left sided neglect has been associated with lesions within the right parietal lobe (Heilman, Watson, Valenstein, & Damasio, 1983), right sided neglect, which tends to be less common and less severe than left sided neglect, is associated with lesions within the left parietal lobe (Denes et al., 1982).

The work of Posner and colleagues (Petersen, Robinson, & Morris, 1987; Petersen, Fox, Posner, Mintun, & Raichle, 1988; Posner, Petersen, Fox, & Raichle, 1988), in combining the COAT with neuroimaging procedures, has been instrumental in identifying the neuroanatomical substrates of the *orienting of attention*. Specifically, the orienting of visual selective attention has been found to be under the control of the posterior parietal lobes, the lateral pulvinar nucleus of the thalamus, and the superior colliculus of the midbrain tectum (Posner & Petersen, 1990). Furthermore, visual orienting also requires access to the executive network within the frontal lobes and, in particular, the anterior cingulate, which is located within the midline frontal areas (Posner & Petersen, 1990). The anterior cingulate has also been found to have projections in to the posterior parietal lobe and, as a result, it plays an important role in tasks requiring the posterior attention system, as well as in language tasks (Posner & Petersen, 1990). In addition, it has been suggested that there is a hierarchy of attentional systems in which the anterior system can pass control to the posterior system

(Posner et al., 1989). Thus, as the visual orienting task becomes more automated through practice, it is likely that the demands upon the anterior cingulate are reduced.

The frontal lobes have also been implicated in both *selective* and *sustained* attentional processes. More specifically, patients with right, but not left, frontal lesions have displayed impairments on a sustained attention task (Wilkins, Shallice, & McCarthy, 1987). The frontal lobes have also been frequently implicated in studies with regard to their role as a regulator/executive controller of attentional processes, particularly in relation to the function of the *Supervisory Attentional Control* system (Shallice & Burgess, 1993; Stuss & Benson, 1986). However, while processes associated with selecting relevant stimuli and inhibiting irrelevant ones (i.e. selective attention) appear to have their neurological substrates in the frontal lobes, disruption to the thalamic projection system has also been found to be associated with increased distractibility (Stuss & Benson, 1986).

Neuroimaging studies have therefore identified a range of cortical and subcortical areas associated with the various components of attention. Disruption to any of these regions within the brain may lead to one or more of the components of attention being compromised.

2.5 Posner's Model of Attention

Despite the various paradigms and divergent methodologies that have, in the past, been used to study attention, recent years have seen a significant convergence of opinion within the literature with regard to the component processes that constitute attention (refer to section 2.3). In addition, there is now a model of attention that attempts to explain the relationship between these components of attention and their neuroanatomical substrates. This model, developed by Posner and Petersen (1990), consists of three major interconnected components or networks of attention, each of which can be linked to an underlying neuroanatomical system (Posner & Petersen, 1990). These networks include a *selection* or *executive* network, which is responsible for selecting relevant stimuli and inhibiting irrelevant ones, a *vigilance* network, which maintains readiness to respond, and an *orientation* network, responsible for engaging, moving and disengaging visual attention in space (Posner & Petersen, 1990). As neuroimaging and lesion studies have identified the frontal lobes as being activated during tasks involving the selection/executive and vigilance networks, these attentional networks were grouped together under the rubric of the *anterior attention system* (Posner & Raichle, 1994). In contrast, the orienting of attention has been shown to produce increased activity of the posterior parietal lobe (Posner et al., 1989). As a result, the *orienting network* has been assigned to a system within the Posner model known as the *posterior attention system* (Posner & Raichle, 1994) [refer to Figure 2.4].

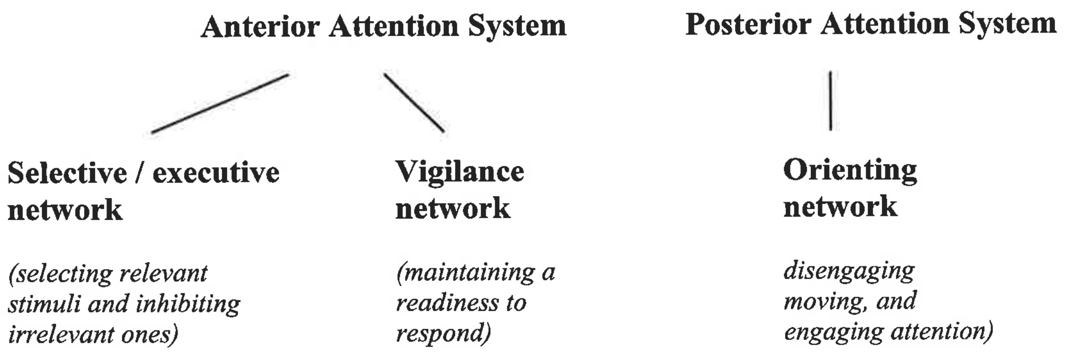


FIGURE 2.4 Posner's (Posner & Raichle, 1994) model of attention

Studies of cerebral blood flow under dual task conditions have revealed significant interactions between the anterior and posterior systems (Posner et al., 1989). This interaction is demonstrated by the finding that both healthy participants and patients with parietal lesions produce slower overall RTs and orient more slowly to cues in dual task situations involving both a Language task and the COAT (Posner & Raichle, 1994). The additional load placed upon the anterior system, caused by the introduction of a secondary task, impacts upon its ability to carry out executive functions and, consequently, affects the posterior attention system (i.e. reducing performance on the COAT). Thus, although the visual orienting of attention is controlled by the posterior system, visual orienting still requires access to the anterior executive network, under dual task conditions, in order for attentional resources to be allocated (Posner & Raichle, 1994).

Leon-Carrion et al. (1996) attempted to assess whether the model proposed by Posner and Petersen (1990), which was derived essentially from experimental methods, could be duplicated using psychometric/neuropsychological measurement techniques. Using factor analytic techniques to analyse the neuropsychological test scores obtained by a group that had sustained a TBI, Leon-Carrion et al. (1996) found a four factor structure, consisting of *perceptual and motor speed*, *vigilance and alertness*, *encoding*, and *shifting*. In comparing their data to the Posner and Petersen (1990) model, Leon-Carrion et al. (1996) suggested that their first two factors (*perceptual and motor speed* and *vigilance and alertness*) corresponded to Posner's posterior attention system and that factors three (*encoding*) and four (*shifting*) represented the anterior attention system. Leon-Carrion et al. (1996) concluded that the Posner model was, in fact, stable and could be derived independently of diagnostic group.

2.6 Attention and Traumatic Brain Injury

In healthy individuals, deficits in attention are one of the most common causes of failure to learn and to accurately observe what is occurring in their environment (e.g. driving) (Geschwind, 1982). Although in educational settings it is common for attention to be implicated when students are not performing well at their work, in clinical settings it is more likely for the psychologist or neurologist to point to other cognitive processes, such as comprehension or memory, rather than attention, to explain such deficits in performance

(Geschwind, 1982). Despite this, deficits in attention are perhaps one of the most pervasive and, at the same time, least understood cognitive-behavioural disturbances found in neuropsychological contexts (Mirsky, Anthony, Ahearn, & Kellam, 1991).

Difficulties with concentration and attention are amongst the most common problems reported by people following non-penetrating TBIs (Gronwall, 1987; McKinlay, Brooks, Bond, Martinage, & Marshall, 1981; van Zomeren & Brouwer, 1987). In fact, a significant proportion of patients with severe TBI continue to report such difficulties more than two years post-injury (Ponsford, Olver, & Curran, 1995). These attentional deficits compromise virtually all other cognitive processes including memory, learning, and reasoning (Schmitter-Edgecombe, 1996) and, as a result, provide a major obstacle to rehabilitation and to the patient's successful reintegration into the community. In everyday life, these difficulties present themselves as increased distractibility (McKinlay et al., 1981; Schmitter-Edgecombe & Kibby, 1998) and a tendency to become overloaded when having to deal with more than one thought at a time (Lezak, 1995).

Evidence of a deficit in *focussed* attention using a reaction time task was reported by Godefroy, Lhullier, & Rousseaux (1996). A deficit in *focussed* attention was also found by Schmitter-Edgecombe and Kibby (1998) in a group of severe TBI participants. Using a visual selective attention task, Schmitter-Edgecombe and Kibby (1998) found that when the target-distractor similarity was high, severe TBI participants had much more difficulty than Controls in ignoring irrelevant information and focusing their attention.

With regard to *divided* attention, Hartman, Pickering, and Wilson (1992) used a primary visual tracking task in conjunction with a variety of secondary tasks and found that a group of severe TBI participants performed significantly worse than the Control group on this *divided* attention task. Godefroy et al. (1996) also found evidence of a deficit in *divided* attention in their TBI group when responding to the presentation of a reaction time task and secondary task. Similarly, Park, Moscovitch, and Robertson (1999), using both the PASAT and a secondary recognition task, reported evidence of a *divided* attention deficit following severe TBI. Both *divided* and *focussed* attention deficits following severe TBI have also been reported on a number of sub-tests from the Test of Everyday Attention (TEA; Robertson et al., 1996).

Sustained attention deficits have also been found following severe TBI. For example, Whyte, Polansky, Fleming, Coslett, and Cavullucci (1995) reported that severe TBI participants had difficulty in maintaining stable performance over time, independent of distracting events. Using the Continuous Performance Test, Loken, Thornton, Otto, & Long, (1995) found evidence of a *sustained* attention deficit following severe TBI, a deficit that was evidenced by a decline in vigilance over time. *Sustained* attention deficits amongst severe TBI sufferers have also been found using the Lottery sub-test of the TEA (Robertson et al., 1996).

Although a number of studies have identified a range of attentional problems following severe TBI, there have also been studies that have failed to find evidence of any such deficits. For example, a number of studies that have used the Stroop Colour Word test to assess *focussed* attention, have found no decrement in the interference effect on this task (Chadwick et al., 1981; Stuss et al., 1985; van Zomeren et al., 1984). As a result, these authors have concluded that there is no evidence for a focussed attention deficit following TBI. In addition, Brouwer and Wolffelaar (1985), in using an auditory vigilance task to assess *sustained attention*, also found no evidence of a deficit in their TBI sample.

Deficits in the *orienting* of visual attention have also been reported following severe TBI. Cremona-Meteyard, Clark, Wright & Geffen, (1992) found that when TBI participants were presented with a visual cue indicating the location of an imminent target (i.e. COAT), they were not able to take advantage of this cue (Benefit) and produce faster RTs. This finding within the TBI group was interpreted by Cremona-Meteyard et al. (1992) to indicate an impairment in the pre-alignment (orienting) of attention to a cued location.

Thus, there are some conflicting results with regard to the presence of attentional deficits following severe TBI. Furthermore, where deficits have been detected, there has been some debate about whether these deficits reflect genuine deficits in attention. Ponsford and Kinsella (1992) and van Zomeren and Brouwer (1987), for example, argue that the poorer performance of TBI patients can be explained in terms of a reduced speed of information processing, rather than a specific attentional deficit.

A number of reasons have been put forward to explain the conflicting findings reported above. While these reasons will be discussed in more detail in Chapter 4, the multifactorial nature of many of the measures used, as well as their atheoretical basis and poor ecological validity, have been identified as the key limitations of currently available measures of attention. Such limitations have lead some authors to conclude that many of these measures are not sufficiently sensitive to detect specific attentional deficits (e.g. Ponsford & Kinsella, 1992; Spikman et al., 1996). In addition, the relatively low correlations that have been found between many of these measures and the reports of TBI sufferers and their significant others (Gronwall, 1991; Ponsford & Kinsella, 1991), further highlights the limitations of these measures.

The current findings within the literature therefore present an unclear picture with regard to the nature of attentional function following severe TBI and the most appropriate means by which to assess it. There is, therefore, a need to identify measures of attention that are able to assess specific attentional processes, independently of other cognitive processes (e.g. memory, speed of information processing). The COAT, which was briefly described in section 2.3.3, appears to address these criteria. As the COAT examines attention at a very fundamental level (i.e. the orienting of attention to an event), it is able to minimise the contribution of other cognitive processes to task performance. In addition, the task parameters can be altered to reduce the impact of reduced speed of information processing. As a result, the COAT would seem to be an ideal measure to assess attention following severe TBI.

A second measure which appears to address some of the limitations of many of the current measures of attention is the Test of Everyday Attention [TEA] (Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994). Although this test will be examined in detail in Chapter 4, the fact that it has been based upon an attentional model, and that it includes more ecologically valid measures, suggests that it also can make an important contribution to our understanding of attention following severe TBI. Surprisingly, there have been few studies that have examined the performance of severe TBI groups on the TEA.

2.7 Summary

The study of attention emerged as a central topic within psychology in the early 1900s. However, it was not until the 1950s that the development of theories, and the experimental testing of these theories, gained prominence. Unfortunately, early attentional research was compromised by the absence of a clear definition of attention and its associated components. As a result, research and theory development lagged behind research in other areas of cognitive function, such as memory, learning, and language (Mirsky et al., 1991). Given the initial absence of a clear definition or theoretical model of attention, a significant divergence in the experimental and theoretical paradigms used to study attention also developed. This divergence has made it difficult to review attentional theory as there has been no universal language or set of constructs by which to compare the varying studies (Cohen et al., 1993). In fact, Cohen et al. (1993) suggested that the similarities and differences between attentional theories are often obscured because of the differences in the language and paradigms that are used. In addition, the limitations of many clinical tests of attention and, in particular, their multifactorial nature, atheoretical basis, and poor ecological validity have also restricted attentional research. Furthermore, these limitations have restricted the extent to which interactions between attention and other cognitive processes, particularly memory, have been investigated.

Although the study of attention has historically been plagued by divergent paradigms and methodologies, within the last decade there has been a significant convergence of views within the attentional literature, such that attention is no longer thought to be a unitary process; rather it is thought to consist of a series of interrelated components (Parasuraman & Davies, 1984; Posner & Petersen, 1990). These components include arousal, hemi-attention, orienting, focussed attention, divided attention, sustained attention, and supervisory attentional control (Chan, 2001; Parasuraman & Davies, 1984). In addition, the neuroanatomical substrates of these attentional components have been identified.

The relationship between these attentional components and their neuroanatomical substrates has been explained by Posner's model of attention (Posner & Petersen, 1990; Posner & Raichle, 1994). This model, which is probably one of the most influential models of attention, consists of three separate networks. These networks include (1) a *selective/executive* network, which is responsible for selecting relevant stimuli and inhibiting irrelevant ones, (2) an *orienting* network, responsible for the visual orienting of attention, and (3) a *vigilance* network, responsible for maintaining a preparedness to respond in the absence of external cues. Of particular importance has been the confirmation of the structure of this model using the psychometric method (Leon-Carrion et al., 1996). More recently, Robertson et al. (1994;1996) found further support for the structure of this model using a combination of established neuropsychological tests and the TEA. There is now, in fact, a remarkable consistency in the concepts and models originating from these experimental and neuropsychological/psychometric approaches to attention (Cohen et al., 1993).

The model devised by Posner has been closely associated with the development of the experimental procedure known as the COAT (Posner, 1980; Posner et al., 1982; 1984; 1987). The COAT, also devised by Posner and colleagues, appears to be able to assess attention at its most fundamental level, namely the *disengaging*, *moving*, and *engaging* of visual attention (Posner, 1980; Posner et al., 1982; 1984; Posner & Petersen, 1990). As a result, performance on this task does not appear to be influenced by the factors that have compromised many other clinical and experimental tests of attention, namely their multifactorial nature and lack of theoretical underpinning. The Posner model has also served to underpin the development of the Test of Everyday Attention (TEA) (Robertson et al., 1994), a test devised to assess a variety of attentional components using ecologically valid test materials. This test will be dealt with in detail in Chapter 4.

While a range of studies have reported deficits in attention following TBI (Godefroy, Lhullier, & Rousseaux, 1996; van Zomeren, 1981; Hartman, Pickering, & Wilson, 1992; Park, Moscovitch, & Robertson, 1999; Loken, Thornton, Otto, & Long, 1995; Stuss, Pogue, Buckle, & Bondar, 1994; Stuss, Stetham, Hugenholtz, & Richard, 1989; Whyte, Polansky, Fleming, Coslett, & Cavullucci, 1995), the limitations of the measures used have made the exact nature of these deficits difficult to define.

This thesis therefore sought to investigate the nature and assessment of attentional function following severe TBI using both the COAT and the TEA. It also compared the performance of TBI participants on a range of conventional neuropsychological measures of attention against their performance on the TEA, and a self/significant other questionnaire of attentional problems. While the review of the literature within this chapter identified a number of components of attention (i.e. arousal, hemi-attention, orienting, selective attention, sustained attention) the focus of this thesis was upon attentional *orienting*, *selective* (focussed and divided), and *sustained* attention, as it was these three components that formed the basis of the Posner model.

A central aim of this thesis was to test the model devised by Posner. Given the frontal, temporal, and DAI sequelae of TBI, and the relatively well preserved parietal / posterior regions, the Posner model would predict deficits in the *anterior attention system* (i.e. selective / executive network, and vigilance network), but intact *posterior attention system* (i.e. orienting network).

The general aims of the thesis are outlined below. More detailed aims are included within the respective chapters.

2.7.1 Project Aims

The overall aim of this thesis was to investigate the nature of attentional deficits following severe TBI. In particular, the thesis examined:

(1) the ability of the COAT to detect specific attentional deficits following severe TBI (Chapter 3).

(2) the ability of the theoretically-based Test of Everyday Attention to detect deficits in attention following severe TBI (Chapter 4).

(3) the ability of a battery of conventional neuropsychological tests to detect attentional problems following severe TBI (Chapter 4).

(4) the relationship between both patients' and significant others' ratings of attentional problems and each of the objective measures of attention (Chapter 4).

(5) the recovery of attentional function following severe TBI, using

  (a) a cross-sectional analysis to compare TBI participants who were in the early (< 12 months post-injury) and late stages (> two years post-injury) of their recovery; and

  (b) a longitudinal analysis to determine whether there was any change in performance when participants were re-tested 12 months after the initial assessment (Chapter 5).

(6) the impact of attention on memory performance following severe TBI (Chapter 6).

CHAPTER 3

THE ORIENTING OF ATTENTION

3.1 Introduction

Cognitive psychologists have long sought to identify the internal mental operations involved in attention. Much of this research has focussed upon the 'higher level' attentional processes that are responsible for analysing various characteristics and features of stimuli prior to selection for further analysis. However, there are a number of authors who have attempted to examine attention at its most basic level; namely the orienting of attention (e.g. Posner, 1980; Posner, Cohen, & Rafal, 1982; Umilta, 1988). Attention can be oriented (directed) toward information presented at the 'sensory surface' or to information stored in memory (Posner et al., 1982). This orienting of attention results in information being processed more efficiently than non-attended information (Umilta, 1988).

Most of the work on the orienting of attention has been based upon the orienting of visual attention. Moreover, there are a variety of methods and paradigms that have been used to examine the orienting of attention to different positions in space and the resultant efficiencies in the processing of information at these locations (Umilta, 1988). Some examples of the experimental paradigms that have been used include stimulus detection tasks (Bashinski & Bacharach, 1980), simple and choice response times (Posner, 1980), naming latencies (Ericksen & Hofman, 1972), and amplitude and latency of evoked potential responses (Rugg, Milner, Lines, & Phalp, 1987). Of these approaches, the work of Posner has been the most extensive and influential with regard to developing an attentional orienting paradigm (Posner, 1980; Posner, Cohen, & Rafal, 1982; Posner, Inhoff, Friedrich & Cohen, 1987; Posner & Raichle, 1994; Posner, Walker, Friedrich, & Rafal, 1984). In addition, the Covert Orienting of Attention Task (COAT), developed by Posner and colleagues has, according to Maruff, Yucel, Danckert, Stuart, and Currie (1999), made an important contribution to the development of neuropsychological theories of attention, particularly to the model of Posner and colleagues, which was described in Chapter 2 (Posner, 1980; Posner & Raichle, 1994).

This chapter outlines the COAT in detail and discusses the underlying attentional processes that the task attempts to identify. The three studies reported within the remainder of this chapter examine the covert orienting of visual attention following TBI under a number of different experimental conditions. *Study 1* examines the orienting of attention in response to centrally presented (directional) cues in the horizontal plane. In addition, the effect of a secondary (language) task is assessed. *Study 2* is essentially a replication of *Study 1*, except that stimuli are presented in a vertical, as opposed to a horizontal, plane. *Study 3* compares the exogenous (reflexive) and endogenous (controlled) orienting of attention in response to peripheral cues in the horizontal plane. The chapter concludes by discussing the extent to which the findings of these three studies furthers our understanding of the nature of attention deficits following severe TBI and the implications of these findings for the assessment and rehabilitation of these deficits.

3.2 The Covert Orienting of Attention Task (COAT)

The COAT involves a simple detection and reaction time (RT) task that examines the effects of valid, invalid, and neutral spatial cues upon RT (Posner, 1980; Posner et al., 1982, Posner et al., 1984; Posner et al., 1987). Valid cues, as their name suggests, correctly indicate the location of the imminent target, while invalid cues direct attention to the opposite side of the visual field to where the target is to be presented. Neutral cues, on the other hand, indicate that the target is imminent, but give no directional information as to its location.

The cues presented within the COAT can be of either a directional nature (e.g. a centrally located left or right pointing arrow - refer to Figure 3.1a), or they can be presented peripherally at a possible target site (i.e. the illumination of a square around the imminent target location - refer to Figure 3.1b). Detailed descriptions of the centrally and peripherally cued COATs are provided in sections 3.2.1 and 3.7.3.2, respectively.

The COAT also has the facility to vary the interval between cue and target presentation. By allowing the participant more time to orient their attention to the target location, the contribution of speed of information processing to task performance can be reduced. Although the COAT stimuli have most commonly been presented in a horizontal plane (Cremona-Meteyard et al., 1992; Posner et al., 1982, 1984, 1987; Wright et al., 1994), some studies have examined the orienting of attention in the vertical (Rizzolati et al., 1987) and sagital planes (Gawryszzewski et al., 1987).

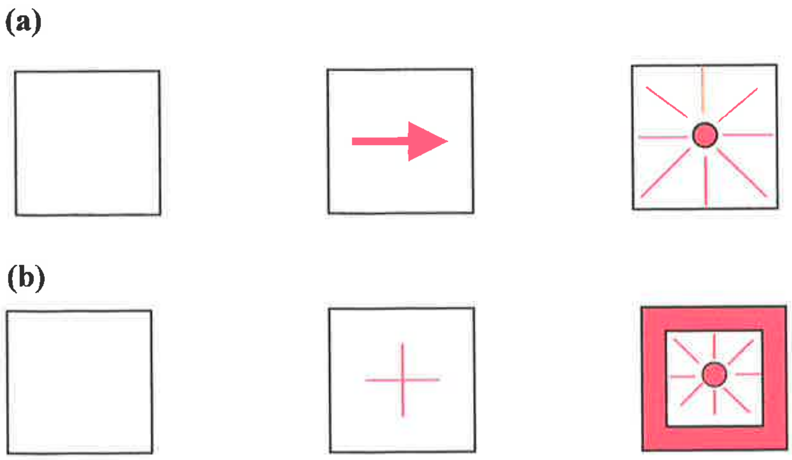


FIGURE 3.1 (a) COAT central directional and (b) COAT peripheral cue presentation. The target which follows cue presentation is also shown.

3.2.1 Posner's Centrally Cued COAT

In the central directionally cued COAT, cues are presented at a central fixation point and consist of an arrow pointing either in the direction of the imminent target (valid cue) or in the opposite direction (invalid cue). Neutral cues take the form of a cross (+) presented at a central fixation point and do not provide any directional information. In addition, there is an equal probability of the target appearing in either the left or right visual fields following a neutral cue. The probability of the directional cue being correct (i.e. valid) or incorrect (i.e. invalid) can be manipulated within the experimental paradigm. This is done to determine whether participants are able to override reflexive (exogenous) orienting processes with controlled (endogenous) processes. For example, while an 80% probability condition provides a high probability that the cue will be valid and results in the participant responding to the cue accordingly, if participants responded to this cue in the same way to a 20% probability condition, we would conclude that they were not able to override their reflexive (exogenous) orienting processes (Maruff, Pantelis, Danckert, Smith, & Currie, 1996).

Studies that have investigated the effects of valid and invalid cues have, in general, used an 80% valid, 20% invalid ratio (e.g. Cremona-Meteyard et al., 1992; Posner et al., 1982; 1984; 1987). The effect of the valid or invalid directional cues upon the orienting of visual attention is measured by comparing RTs in response to these conditions against RTs to a neutral cue. Healthy participants have been found to display faster RTs to valid than neutral cues (Cremona-Meteyard et al., 1992). This difference is referred to as a *Benefit*, as it measures the extent to which a participant can take advantage, or benefit, from the information provided by the cue. Healthy participants also display slower RTs to invalid than neutral cues (Cremona-Meteyard et al., 1992). This difference has been referred to as *Cost*, as it measures the extent to which the participant is disadvantaged by orienting their attention in the incorrectly cued direction (Posner & Raichle, 1994).

While the calculation of Benefits and Costs provides an important measure of the extent to which participants are able to utilise the valid and invalid cues to orient their attention, Jonides and Mack (1984) have questioned the utility of using a cost-benefit analysis in relation to neutral cues. These concerns relate to the assumption that, for a cost-benefit analysis to be meaningful, "... neutral and informative cueing conditions must be identical with respect to all processing consequences of the cue except the specific preparatory effect elicited by the informative cue" (Jonides & Mack, 1984, p. 33). Thus, Jonides and Mack (1984) caution against using neutral cues if these criteria cannot be met. In fact, some studies have addressed this issue by only calculating the difference between the RTs in response to the invalid and valid cues (e.g. Pavese, Heidrich, Sohlberg, Laughlin, & Posner, 1998; Posner et al., 1987; Posner et al., 1989). This value has become known as the *Validity* effect (Swanson et al., 1991).

In addition to the calculation of the Benefit, Cost, and Validity effects associated with valid and invalid cues, Posner et al. (1984) also claimed to be able to "... distinguish more finely the mental operations involved in target detection" (p. 1864). For example, if a valid cue is presented, and sufficient time is allowed for attention to orient to that location after the cue has appeared, then Posner (Posner et al., 1982, 1984, 1987; Swanson et al., 1991) has argued that the only mental operation to be performed when the target appears at that location is for the target to be *engaged*. In contrast, where the participant is fixated at a central point and is given no cue (or a neutral cue), when the target is presented, he/she must first *move* to the target location and then *engage* the target. Finally, if an invalid cue is presented, then the person must *disengage* attention from the cued location, *move* to the target location and *engage* the target (Posner et al., 1984). Thus, a reduced Cost (from invalid cues) but normal Benefit (from valid cues) when the COAT is used with clinical samples, has been interpreted as a tendency to more readily disengage attention (than healthy controls). In other words, a reduced Cost may be seen as a difficulty in maintaining attention (Wright, Burns, Geffen & Geffen, 1990). On the other hand, a reduced Benefit but normal Cost (compared to controls) is thought to indicate difficulties in pre-aligning (engaging) attention (Cremona-Meteyard et al., 1992).

Posner and colleagues have also introduced a dual task condition to the original experimental paradigm in order to assess a participant's ability to divide their attention, by combining both the COAT and a simple phoneme detection task (Posner et al., 1987). Using a group of nine participants with unilateral lesions of the parietal lobe, Posner et al. (1987) found that the introduction of the secondary language task delayed the orienting of attention to the spatial cues on the COAT, compared to single task conditions. In addition, performance on the secondary task declined compared to when it was administered under single task conditions (Posner et al., 1987). This finding highlights the importance of dual task conditions in the assessment of attention.

3.3 The COAT in Clinical Populations

The COAT has been widely used in the experimental literature and has identified specific attentional deficits in a variety of diagnostic groups. For example, patients with Parkinson's Disease showed a reduced Cost but normal Benefit on the COAT, which resulted from a tendency to disengage from attended locations more readily than Controls (Wright, Burns, Geffen, & Geffen, 1990). This finding was interpreted by Wright et al., (1990) to indicate problems in maintaining attention. Wright, Cremona-Meteyard, Geffen, and Geffen (1994) found that participants with Alzheimer's Disease were slower to respond to the neutral cue than valid or invalid cues, leading them to conclude that this group were compromised with regard to dividing their attention. While children with attention deficit hyperactivity disorder

(ADHD) have been found to exhibit normal orienting patterns at a short cue-target interval (i.e. 100 ms), differences in the orienting patterns of ADHD and control participants are evident at longer cue-target intervals (Swanson et al., 1991). This difference was interpreted by Swanson et al. (1991) to reflect a failure of ADHD participants to sustain their attention.

A study of patients with Progressive Supranuclear Palsy revealed that only the latency of covert orienting was affected, with the ability to disengage, move and engage attention seemingly intact (Posner et al., 1982). Thus, although the reaction times in response to targets within this group were reduced, they were still able to orient their attention in response to valid and invalid cues. Damage to the parietal lobe as a result of a cerebral vascular accident, has been found to produce a deficit in the disengage operation when the target was contralateral to the lesion (Posner et al., 1984). Problems in the ability to disengage attention suggest an inability of the individual to shift attention from its current focus in response to new cues and targets (Posner & Raichle, 1994). Deficits in engaging the target have also been found in this patient group (Posner et al., 1984), and are thought to reflect an impairment in the ability to direct attention to, and maintain attention at, a specific location (Cremona-Meteyard et al., 1992). Thus the COAT has been found to detect attentional deficits in a range of diagnostic groups.

3.3.1 The COAT and Traumatic Brain Injury

To date, only a relatively small number of studies have used the COAT to examine the orienting of attention following severe TBI (e.g. Cremona-Meteyard et al., 1992; Cremona-Meteyard & Geffen, 1994; Pavese et al., 1998; Sandson et al., 1988). Importantly, there do not appear to have been any studies that have examined the COAT performance of TBI participants under dual task conditions.

Given the pathophysiology of TBI (i.e. frontal and temporal lobe damage, DAI, and relatively intact parietal lobes) and our knowledge of the neuroanatomical substrates underlying attention, there should be a greater disruption of the frontally located anterior attention system, following severe TBI. Thus, as the orienting of attention is principally a function of the posterior attention system, we would predict intact COAT performance in TBI participants under single task conditions. Furthermore, the additional load placed upon the anterior (executive) attention system by the introduction of a dual task condition, while resulting in a reduction in performance on the COAT in both healthy and TBI participants, should result in a significantly greater decrement in the TBI group. This predicted decrement can be explained in terms of the increased demands placed on an already compromised anterior attention system, amongst TBI participants.

Consistent with these predictions, an early study by Sandson et al. (1988) found that, while severe TBI participants were slower than controls, they were still able to orient their attention in a similar way to the Control group. These findings have been supported by a recent study which also found that, although the overall reaction times (RTs) of the TBI group were slower, their pattern of orienting to the various cues was similar to the Control group (Pavese et al., 1998). The results from the Pavese et al. (1998) study suggest that there was a generalised slowing of RTs, possibly as a result of reduced speed of information processing, but there was no specific deficit in attentional orienting. However, it should be noted that six of the 11 Pavese et al. (1998) patients had a loss of consciousness (LOC) of less than one hour, which places them within the mild to moderate range of severity of TBI. More severe TBI patients may have produced a different pattern of orienting.

Indeed, deficits in the orienting of attention in severe TBI participants have been found. Cremona-Meteyard et al. (1992) found that, while there were no overall differences in the

RTs of their severe TBI and Control groups, the TBI participants displayed a significantly reduced Benefit in response to valid cues. This was interpreted as indicating an impairment in the ability to prealign attention with a cued location. Cremona-Meteyard and Geffen (1994) subsequently replicated these findings in a group of mild TBI participants who were tested within two weeks of their injury. These participants displayed an overall improvement in RT when they were tested 12 months later but continued to display a reduced Benefit.

Although there are divergent findings in relation to the performance of TBI participants on the COAT, the findings of Cremona-Meteyard et al. (1992, 1994) suggest that the COAT warrants a more detailed examination in order to assess its ability to identify discrete attentional deficits that cannot be explained solely in terms of reduced speed of information processing. As mentioned, this experimental paradigm has the potential to partial out speed of information processing factors by manipulating the cue-target intervals. If TBI participants are presented with increasingly longer cue-target intervals, sufficient time should be allowed for them to move their attention to the cued location. Any disproportionate reduction in RT in response to valid or invalid cues could therefore be explained in terms of deficits in the ability to orient attention. As a result, the COAT appears to be a useful vehicle by which to examine discrete attentional processes in persons who have sustained a TBI.

The remainder of this chapter is devoted to three studies which examine the COAT performance of severe TBI participants. Specifically, these studies investigate the orienting of attention using a *horizontal* presentation of the COAT with *central* cues (Study 1), a *vertical* presentation of the COAT with *central* cues (Study 2), and a *horizontal* presentation of the COAT with *peripheral* cues (Study 3). In addition, two of these studies (Study 1 and Study 2) involve a dual task condition in order to assess the orienting of visual attention when attention is divided.

3.4 Study 1[1]

(Horizontal presentation – central directional cues)

3.4.1 Aims and Hypotheses

Study 1 sought to determine the replicability of the Cremona-Meteyard et al. (1992) finding that severe TBI patients exhibit problems in orienting their attention. This study therefore compared the performance of a severe TBI and Control group in response to various cues, delivered at different cue-target intervals, on the horizontal COAT. In order to assess divided attention, the COAT was also presented under both single and dual task conditions. Notably, the current study included a substantially larger sample size than the Cremona-Meteyard et al. (1992) study.

It was hypothesised that:

Hypothesis 3.1: *Group differences in the orienting of attention*

(a) There would be a significant difference between the TBI and Control groups in the way they oriented their attention in response to different types of cues (i.e. valid, neutral & invalid), demonstrated by a significant Group by Cue-Type interaction in a repeated measures analysis of variance (ANOVA) of the COAT data.

(b) Based on the findings of Cremona-Meteyard et al. (1992), it was further predicted that TBI participants would display reduced *Benefit* (neutral RT– valid RT), *Cost* (invalid RT– neutral RT) and *Validity* (i.e. invalid RT minus valid RT) effects on the COAT when compared to Controls. These effects would be confirmed by significant Group by *Benefit*, Group by *Cost*, and

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[1] This study is published in Bate, Mathias & Crawford (2001a). Note that research subsequent to this publication questions the validity of the NART following severe TBI and so, unlike Bate et al. (2001a), the NART-R was not used as a covariate to control for differences in premorbid IQ.

Group by *Validity* interactions when repeated measures ANOVAs are performed on the COAT data.

Hypothesis 3.2: *Group differences in the impact of reduced processing time upon the orienting of attention*

Given the documented evidence of a reduction in the speed of information processing following severe TBI (e.g. Ponsford & Kinsella, 1992; van Zomeren & Brouwer, 1987), the differences in orienting between TBI and Control groups would be most apparent at shorter cue-target intervals. However, when given more time to process the cues, the differences in the attentional orienting patterns between the two groups would not be significant. This hypothesis would be confirmed by

(a) a significant interaction between Group, Cue-Type and Cue-Target Interval, and

(b) significant Group by *Benefit* by Cue-Target Interval, Group by *Cost* by Cue-Target Interval, and Group by *Validity* by Cue-Target Interval interactions when repeated measures ANOVAs are performed.

Hypothesis 3.3: *Group differences on the COAT under dual task conditions.*

While both groups would be expected to perform more poorly on the COAT under dual task conditions (compared to the single task conditions), the decrement in performance was expected to be greater for the TBI than the Control group. This hypothesis would be supported by a significant main effect for Task-Type and a significant Group by Task-Type (single vs dual) interaction effect in ANOVA. The decrement in performance of the TBI group on the COAT under dual task conditions would also be reflected in reduced *Benefit*, *Cost* and *Validity* effects. These effects will be supported by significant Group by *Benefit* by Task-Type, Group by *Cost* by

Task-Type, and Group by *Validity* by Task-Type interactions, respectively, when repeated measures ANOVAs are performed on the data.

Hypothesis 3.4: *Group differences on the Language task under dual task conditions.*

With respect to the Phoneme Detection (Language) Task, it was hypothesised that while there would be no difference in the performance of the two groups under single task conditions, the TBI group would produce a greater increase in errors under dual task conditions. This prediction would be supported by a significant Group by Task-Type (single vs dual) interaction.

3.4.2 Method

3.4.2.1 Participants

Thirty five participants with severe non-penetrating TBIs and 35 controls took part in this study. The 35 control participants were recruited from the general community and were individually matched as closely as possible to the TBI sample on the basis of age, estimated premorbid IQ, and years of education. Participants, from either group, with a history of major psychiatric disorder, intellectual disability, or other neurological disorders were excluded from the study, as were those who had a hemiplegia of their dominant hand, whose native language was not English, or who had a documented history of substance abuse. Participants were also excluded from the study if they displayed symptoms of hemi-neglect, or if they suffered any visual problems (e.g. field loss, diplopia), as assessed by either the rehabilitation or opthalmological medical consultant.

TBI participants were recruited from consecutive admissions, over a three year period, to an outpatient community rehabilitation program. Severity of injury was classified by the lowest recorded Glasgow Coma Scale score (GCS; Teasdale & Jennett, 1974) in the first 24 hours post injury [GCS $\leq$ 8] and/or a post traumatic amnesia period (PTA) of $>$ 24 hours, as measured by the Julia Farr Post-Traumatic Amnesia Scale (Forrester & Geffen, 1995). Where objective assessments were not available, retrospective reports were used to estimate PTA. The results of CT scans were available for 33 of the 35 TBI participants. Some form of frontal lobe pathology was detected in 24 of these scans. For the remaining nine participants, temporo-parietal pathology was detected in three cases, thalamic pathology in two cases, basal ganglia pathology in one case and, a diagnosis of ‘assumed’ diffuse axonal injury in three cases. Demographic and clinical screening data for both groups are displayed in Table 3.1.

TABLE 3.1 Means and standard deviations for demographic and clinical screening data for the TBI and Control groups

	TBI *(n=35)*		*Controls* *(n=35)*	
Age (years)	28.9	(11.5)	30.2	(10.3)
Gender				
Male	28		20	
Female	7		15	
Education (years)	12.0	(1.5)	12.6	(2.0)
Premorbid IQ Estimate	95.4	(8.6)	101.1	(9.1)
Finger Tapping Speed (preferred hand)	42.6	(8.9)	50.1	(6.8)
GCS	5.6	(3.0)		
PTA (days)	42.5	(35.9)		
Time since injury (days)	843.8	(980.2)		

GCS = Glasgow Coma Scale; PTA = Post Traumatic Amnesia

3.4.2.2 Tasks

Covert Orientating of Attention Task

This task was based upon the COAT originally devised by Posner (1980). Participants were seated at a table in a dimmed room in front of a light emitting diode (LED) display unit. On the table was located a response button which they were required to press, as quickly as possible, with the index finger of their preferred hand in response to the presentation of one of two possible peripheral target lights on the LED display unit. The target lights were presented at eye level and 9 degrees laterally to the left or right of a central fixation point. A chin rest was mounted on the table to ensure that the participant's nasion remained a constant 1 metre from the point of fixation, thus ensuring that the visual angle was preserved.

The specifications for the LED stimulus display unit were based on the units used by Clark, Geffen and Geffen (1989), Cremona-Meteyard et al. (1992), Cremona-Meteyard and Geffen (1994), and Wright et al. (1990) in their COAT studies. The LED unit consisted of a 350 mm long by 38 mm wide metal rod set in a horizontal position (refer to Figure 3.2). The centre of the rod contained 21 symmetrically arranged 3 mm red LEDs. Both directional and neutral cues were generated by the illumination of the appropriate combination of these LEDs. Single 3 mm red target LEDs were located 160 mm to the left and right of the central display.

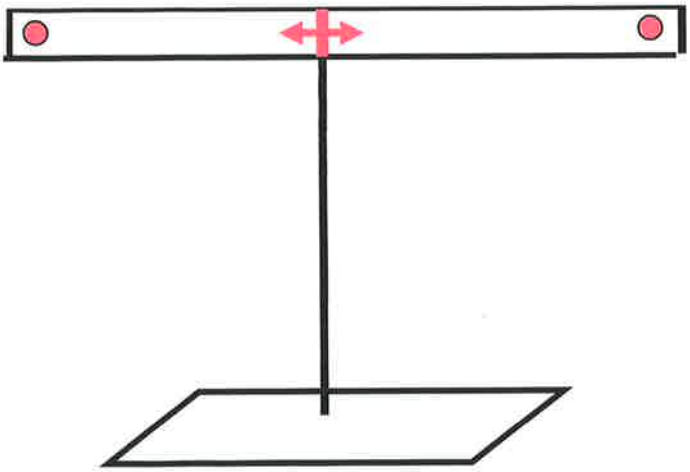


Figure 3.2 **LED stimulus display unit**

Visual cues were presented at the central fixation point at three different intervals before the onset of the target (150, 550, or 1000 ms cue-target intervals). The cue remained on during target presentation, and both cue and target were terminated either by participant response or 900 ms after target onset. The inter-trial interval was fixed at 1000 ms. Consistent with previous studies (e.g. Cremona-Meteyard et al., 1992; Cremona-Meteyard & Geffen, 1994; Wright et al., 1990), responses < 100 ms and > 900 ms following target onset were assumed to indicate anticipatory responses or lapses of attention and so were excluded from further analysis.

Five blocks of trials were presented with 108 trials within each block. On 18 of the 108 trials presented in each block, a *neutral* central cue was presented in the form of a plus sign (+), indicating that the target was equally likely to occur on the left or right. Directional arrow cues (← or →) made up the remaining 90 trials, with the arrows correctly predicting the target side (*valid cue*) on 72 of the trials (66%). The remaining 18 directionally cued trials were *invalid* (16.6%). The probability that the directional arrow cue would be correct (i.e. valid) was therefore 80%. In each block, and in each condition (i.e. neutral, valid, invalid), the number of targets presented to the left and right visual field was equal. Likewise, the three different cue-target intervals were distributed evenly across cue conditions and visual fields. The distribution of trials across the three cue conditions closely replicated the experimental method of Cremona-Meteyard et al. (1992). Median RTs in response to each of the trials were recorded for each participant. Median RTs were chosen to be consistent with the data reported in the Cremona-Meteyard et al. (1992) study, as well as a number of other COAT studies (e.g. Danckert et al., 1998; Posner et al., 1982; 1984; 1987). However, the current study differed from the Cremona-Meteyard et al. (1992) study, which only used one cue-target interval (i.e. 1100 ms), by using three cue-target intervals. This was done in order to examine the effect of speed of information processing.

In order to ensure that only the covert orienting of attention was measured independent of eye movements, both horizontal and vertical eye movements were recorded using four 8mm silver cup electrodes located on the outer canthi of both eyes, and the upper and lower orbit of the left eye (refer to Figure 3.3). The electro-occulargram (EOG) amplifier was set to have a gain of 10,000 times and bandpass filter (6db/octave) settings of 0.03 Hz to 30 Hz at -3db. All inter-electrode impedences were maintained below 5 kOhms throughout the study. Trials were not included in the final data if eye movements exceeded the rejection threshold of 100 microvolts. Each of these settings and parameters were set in line with the studies of Clark et al. (1989), Cremona-Meteyard et al. (1992), and Cremona-Meteyard and Geffen, (1994).

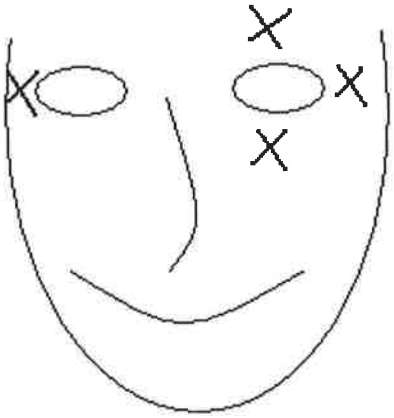


Figure 3.3 Electrode placement for electro-occulargram (EOG)

Phoneme Detection Task

This task was based upon the phoneme detection task incorporated in the work of Posner et al. (1987). Participants were required to count the number of words beginning with the phoneme ‘p’ occurring in a designated list of auditorily presented words. Each list contained 20 nouns, with one to seven words beginning with the phoneme ‘p’. Only nouns were used. At the end of each list, participants were asked how many words from the list began with the sound ‘p’. Thirty word lists were presented using a cassette tape player at the rate of one word every two seconds. All words presented were taken from Kucera and Francis (1967) using the following criteria: maximum frequency = 10,000 per 100,000 words, minimum frequency = 10 per 100,000 words (of natural language text), maximum word length = 9 letters, minimum word length = 4 letters. The scores obtained represented the number of words beginning with “p” in each list that were not detected. The task was administered as both a single task and as a secondary task under dual task conditions (with COAT). The dual task presentation involved participants listening to the tape while at the same time responding to the COAT. At the end of each word list the experimenter paused the COAT and asked "how many"? The experimenter then recorded the participant's response and both the presentation of the COAT and the secondary Language task were resumed.

Finger Tapping Test (Bornstein, 1986; Spreen & Strauss, 1991)

This test was included to control for the effects of deficits in motor speed that may contribute to reduced RTs on the COAT task. Participants were instructed to place the index finger of their preferred hand on a response button and were given 5 consecutive attempts to see how many button presses they could achieve within a 10 second period. The procedure was then repeated with the non-preferred hand. The five consecutive trials for each hand had to be within a five point range from fastest to slowest. Where trials fell outside of this range, additional trials were given so that a sample of 5 trials within a 5 point range of each other could be achieved. The mean number of button presses achieved across the five trials for the preferred and non-preferred hands was recorded. However, only the score from the preferred hand was included in the analyses. The testing apparatus used was an AIM (Cambridge) biosciences laboratory modular unit configured specifically for the current task.

National Adult Reading Test - Revised (UK)

The NART-R UK (Crawford, 1992) is a variant of the widely used NART (Nelson, 1982) and, like the NART, requires participants to read aloud a list of 50 phonetically irregular words. Error scores are then converted to estimated WAIS-R Full Scale IQ scores using the conversion tables provided by Crawford (1992).

The results of Study 1 were originally analysed and published using an estimate of premorbid IQ (NART-R) as a covariate (Bate et al., 2001a). The initial decision to include an estimate of premorbid IQ was based upon the assumption that premorbid IQ had the potential to influence performance on tests of attention. As the two groups were significantly different in terms of their NART-R scores (F(1,68) = 7.15, p = .009, partial $\eta^2 = .095$) it is possible that differences in premorbid IQ, in addition to the effects of TBI, may have contributed to differences between the groups on attentional tests. As a result it was decided to statistically control for premorbid IQ using the NART-R. However, since the publication of the results of Study 1, a number of more recent studies have expressed concern regarding the use of word reading tests, such as the NART, as an estimate of premorbid IQ. For example, Freeman, Godfrey, Harris, and Partridge (2001) found that 30% of their TBI sample had impaired performance on the NART. Using a longitudinal design Riley and Simmonds (2003) administered the NART to a group of 26 severe TBI participants who were within 12 months of a severe TBI, and then retested this group at least 12 months later. Results revealed that the error scores on the initial NART were significantly higher than when retested. Riley and Simmonds (2003) have suggested that cognitive deficits, as a result of the severe TBI, impaired the initial performance, and that recovery in these cognitive functions over the test-retest period resulted in improved performance. Thus, by using the NART-R to control for premorbid IQ, we have been controlling for the effects of TBI itself.

The findings of Freeman et al., (2001) and Riley and Simmonds (2003) are in contrast to earlier studies (e.g. Crawford et al., 1988; Watt & O'Carrol, 1999) who found no differences between the NART scores of their TBI and Control groups. Riley and Simmonds (2003) have suggested that one of the reasons for these differences may be the fact that these studies tested participants who had less severe injuries and who were at a later stage of recovery. It was concluded therefore by Riley and Simmonds (2003) that if the NART is used within the first

12 months of severe TBI then it should be interpreted with considerable caution, and in conjunction with other estimates. In particular the use of demographic data, such as education and socio-economic status, was highlighted (Riley & Simmonds, 2003).

A comparison of the number of years of education completed by the TBI and Control groups revealed no differences (F(1,67) = 1.69, p = .198, - refer to Table 3.1 for means). In addition, an examination of the NART-R test-retest difference scores of the TBI group within the longitudinal study (refer to Chapter 5) revealed some evidence of improvement (t(33) = 2.41, p = .022). As a result, it was decided not to use the NART-R as a covariate in Study 1. However, within the discussion sections following the analyses, comparisons are drawn with the original published analyses of the data which included the NART-R as a covariate (i.e. Bate et al., 2001a, 2001b).

3.4.2.3 Procedure

The data were gathered over two separate sessions. Session 1 involved administering the Finger Tapping Test, NART-R, and two practice blocks of 108 trials of the COAT. The Line Bisection Test (Diller et al., 1974) was administered to screen for the existence of any hemi-neglect. The time taken to complete these tasks was approximately 20 minutes. However, Session 1 also included the neuropsychological measures that were analysed in Study 4. The total duration of Study 1 was therefore approximately 110 minutes. Session 2, was conducted two to seven days later and included the COAT, Phoneme Detection Task, and the Dual task (COAT and Phoneme Detection task combined). The order of presentation of the COAT and Phoneme Detection tasks was counterbalanced to control for effects of order. Five blocks of 108 trials were presented. The dual task (five COAT blocks and the Phoneme Detection task) was then presented after a break of 20 minutes. The total duration of Session 2 was approximately 120 minutes.

3.4.3 Results (Study 1)

All data were analysed using SPSS version 11.5 (SPSS, 2002). Scores on the matching and control variables were analysed first to determine whether there were any significant differences between the two groups. Where significant differences were found, these variables were entered as covariates into the subsequent analyses. The COAT performance of the TBI and Control groups was then compared using an analysis of covariance (ANCOVA).

In addition to the reporting of significance levels within each ANOVA, effect sizes were also calculated as a meaningful effect can be present even though the statistical test lacks sufficient power (due to a small sample size or an imprecise research design) to reach the required significance level (Zakzanis, 2001). SPSS 11.5 for Windows (SPSS, 2002) calculates partial eta squared (η^2) as a measure of effect size. Cohen (1988) has suggested the eta squared values of .01, .06 and .14 as guidelines representing small, medium, and large effect sizes respectively.

Finally, the performance of the TBI and Control groups on the secondary (Language) task was analysed in both the single and dual task conditions. The results from each of the statistical analyses (including significance levels and effect sizes) are outlined within the Appendices.

Matching and Control Variables

While the TBI and Control groups were successfully matched for age and years of education (refer to Table 3.1), there were significant differences between the two groups in terms of premorbid IQ estimate ($F(1,68) = 7.15$, $p = .009$, partial $\eta^2 = .095$), finger tapping speed ($F(1,69) = 15.64$, $p = .000$, partial $\eta^2 = .187$), and gender (χ^2 $(1,60) = 6.69$). However, as discussed previously, it was decided to not control for premorbid IQ estimate (refer to page 80). The contribution of gender to COAT performance has not been examined in previous studies. Given the imbalance of gender within the TBI group, gender differences in COAT performance were examined before proceeding any further. TBI and Control groups were combined and the effects of gender evaluated using one-way ANOVAs for all of the COAT conditions. None of these analyses reached significance (refer to Appendices – Study 1) suggesting that there are no gender effects for the COAT. As a result, only finger tapping speed was entered as a covariate into the subsequent analyses.

COAT

The COAT data was analysed using a four way repeated measures ANCOVA to examine the effects of Group (TBI, Control), Cue-Type (valid, neutral, invalid), Cue-Target Interval (150, 550, 1000 ms), and Task-Type (single, dual) on median RTs, using finger tapping speed as the covariate. The RTs for all single and dual task conditions are reported in Tables 3.2 and 3.3 respectively.

TABLE 3.2 COAT (horizontal) - single task data: means and standard deviations of the median reaction times for each of the cue-target intervals

Cue-Target Interval	Group	Valid Cue	Neutral Cue	Invalid Cue	Benefit (Neutral - Valid RT)	Cost (Invalid - Neutral)	Validity (Invalid - Valid RT)
150 ms	TBI	412.8	429.8	432.0	17.0	2.2	19.2
		(77.2)	(80.5)	(80.2)	(21.0)	(24.0)	(19.2)
	Controls	343.7	365.1	372.9	21.4	7.9	29.2
		(57.5)	(55.2)	(63.0)	(14.9)	(18.6)	(25.2)
550 ms	TBI	341.0	354.1	388.6	13.1	34.5	47.6
		(66.5)	(65.9)	(77.5)	(28.8)	(42.0)	(37.9)
	Controls	285.1	302.8	331.1	17.7	28.3	46.0
		(38.3)	(40.7)	(50.6)	(22.6)	(28.7)	(33.5)
1000 ms	TBI	316.9	326.0	360.4	9.1	34.4	43.4
		(68.0)	(69.3)	(90.4)	(22.3)	(51.3)	(51.3)
	Controls	262.4	276.8	301.9	14.4	25.1	39.5
		(31.9)	(38.1)	(47.2)	(17.8)	(27.1)	(32.3)

TABLE 3.3 COAT (horizontal) - dual task data: means and standard deviations of the median reaction times for each of the cue-target intervals

Cue-Target Interval	Group	Valid Cue	Neutral Cue	Invalid Cue	Benefit (Neutral - Valid RT)	Cost (Invalid - Neutral)	Validity (Invalid - Valid RT)
150 ms	TBI	413.1	440.4	445.4	27.2	5.1	32.3
		(66.6)	(72.4)	(83.1)	(28.7)	(50.5)	(36.1)
	Controls	351.4	366.6	377.6	15.2	11.0	26.2
		(52.8)	(53.6)	(58.0)	(15.8)	(22.7)	(20.1)
550 ms	TBI	349.3	372.6	397.1	23.3	24.6	47.9
		(61.1)	(70.7)	(81.3)	(28.1)	(50.5)	(43.7)
	Controls	294.4	316.1	344.6	21.8	28.4	50.2
		(40.3)	(47.6)	(44.0)	(21.3)	(23.9)	(27.7)
1000 ms	TBI	320.1	335.0	367.6	14.9	32.6	47.5
		(59.6)	(66.0)	(71.4)	(29.2)	(35.1)	(34.2)
	Controls	269.4	289.4	321.9	19.9	32.6	52.5
		(39.3)	(46.0)	(51.6)	(19.7)	(28.2)	(29.1)

A repeated measures ANCOVA revealed significant and medium to large main effects for Group (F(1,67) = 8.89, p = .004, partial η^2 = .117), Cue Type (F(2,134) = 7.39, p=.001, partial η^2 = .099), and Cue-Target Interval (F(2,134) = 45.52, p = .000, partial η^2 = .405). Task-Type was not significant (F(1,67) = 0.44, p = .511, partial η^2 = .006). The main effect for Group confirmed that there was a significant difference in the overall RTs of the TBI and Control groups (across the three cue-type and cue-target intervals), with tables 3.2 and 3.3 revealing that the TBI group were approximately 45 - 70 ms slower than the Control group. With regard to the Cue-Type main effect, participants responded fastest to the valid cues and slowest to the invalid cues, with responses to neutral cues being intermediate to these two cue types. Changes in RT in response to the varying cue types are illustrated in Figure 3.4. The main effect of Cue-Target Interval is illustrated in Figure 3.5 (a) and (b) where it can be seen that, as cue-target intervals increased from 150 ms to 1000 ms, RTs decreased.

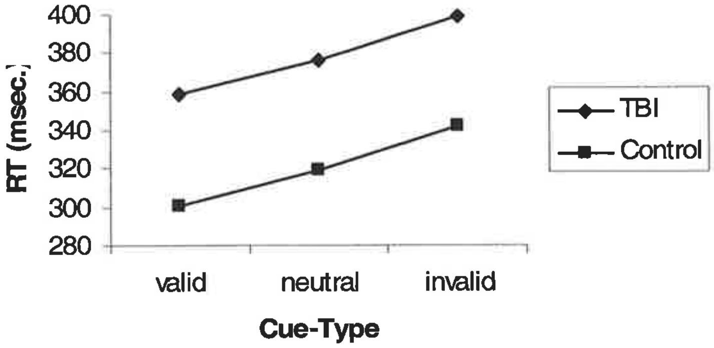
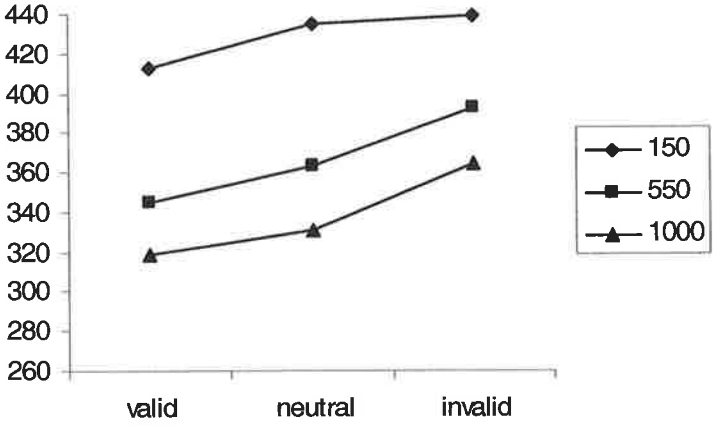


Figure 3.4 **Mean of median reaction times for TBI and Control participants under COAT (horizontal) conditions in response to the three cue-types (valid, neutral, invalid)**

(a) TBI Group



(b) Control Group

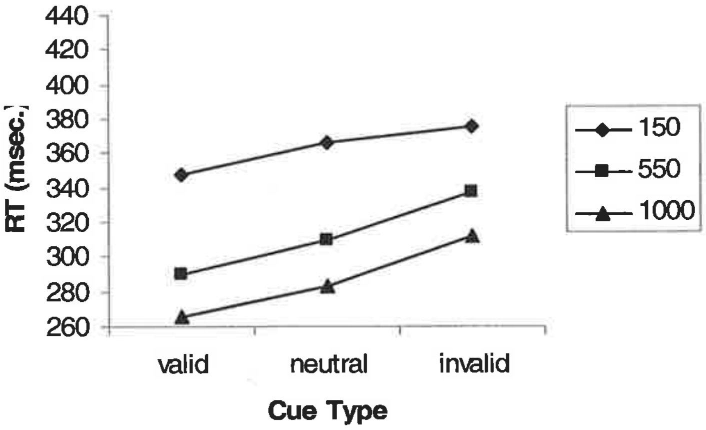


Figure 3.5 Mean of median reaction times for (a) TBI and (b) Control participants under COAT (horizontal) conditions across each of the three cue types (valid, neutral, invalid) and in response to the three cue-target intervals (150, 550, 1000ms)

It was hypothesised that there would be a significant difference between the TBI and Control groups in the way they oriented their attention in response to the valid, neutral, and invalid cues, and that this would be reflected in a significant Group by Cue-Type interaction (Hypothesis 3.1(a)). However, the current analysis did not find a significant Group by Cue-Type interaction (F(2,134) = 0.17, p = .846, partial $\eta^2 = .002$) suggesting that even though the TBI group produced slower RTs, both groups oriented their attention to the three cues in a similar fashion. The similar line gradient displayed by the TBI and Control groups in Figure 3.4 illustrates this similar pattern of facilitation (Benefit) and inhibition (Cost) for both the TBI and Control groups in response to the three cue types. Thus, neither Hypothesis 3.1(a) or (b) were supported.

Speed of Information Processing

It was hypothesised that the TBI group would display deficits in their orienting of attention at a shorter cue-target interval but, given more time (i.e. a longer cue-target interval) to compensate for any reduced speed of information processing deficits, there would be no such differences between the groups (Hypothesis 3.2(a)). However, contrary to this hypothesis, there was no Group by Cue-Target Interval (F(2,134) = 0.38, p = .685, partial $\eta^2 = .006$) or Group by Cue-Type by Cue-Target Interval (F(4,268) = 0.82, p = .514, partial $\eta^2 = .012$) interaction, suggesting that when Cue-Target Intervals were increased, the TBI group displayed the same level of improvement in RTs as the Control group (refer to Figure 3.5). Such a finding suggests that the orienting patterns of TBI participants were *not* compromised by placing greater demands on their speed of information processing. Hypothesis 3.2 was therefore not supported.

Dual Task (COAT)

The absence of a main effect for Task-Type (single, dual) or a Group by Task-Type interaction ($F(1,67) = 0.06$, $p = .804$, partial $\eta^2 = .001$), indicated that the introduction of the secondary (Language) task did not affect COAT performance, nor did it differentially affect the performance of the TBI group. This finding was contrary to the prediction that, under dual task conditions, the TBI group would display a greater decrement in performance (compared to single task performance) than the Control group (Hypothesis 3.3).

Secondary Task (Language) Performance

The mean number of errors made by both groups under both single and dual task conditions are reported in Table 3.4. A Group (TBI, Controls) by Task-Type (Single, Dual) repeated measures ANOVA revealed a significant main effect for Group ($F(1,68) = 19.82$, $p = .000$, partial $\eta^2 = .226$), showing that TBI participants produced significantly more errors than Control participants. There was also a significant Group by Task-Type interaction ($F(1,68) = 11.86$, $p = .001$, partial $\eta^2 = .148$), which indicates that the TBI group produced a greater increase in error rate under dual task conditions. Consistent with Hypothesis 3.4, the performance of the TBI and Control groups was comparable under single task conditions (refer to Table 3.4). However, also consistent with Hypothesis 3.4, when the Language task was combined with the COAT, the TBI group made significantly more errors

TABLE 3.4 Mean (and SD) number of errors for both single and dual task conditions.

	Single Task[1]	Dual Task[2]
TBI (n=35)	0.49 (0.87)	2.60 (2.09)
Control (n=35)	0.20 (0.47)	0.97 (0.75)

1. Single block score represents mean number of errors across 6 lists of 20 words.
2. Dual task score represents the mean number of errors across 30 lists of 20 words.

3.4.4 Summary of Results (Study 1)

The results of this study indicated that the overall RTs of TBI participants were significantly slower than Controls on the horizontal COAT. However, the absence of a significant Group by Cue-Type interaction effect suggested that there were no differences between the TBI and Control groups in terms of how they oriented their attention.

Given the well documented evidence of a reduced speed of information processing following severe TBI (e.g. Ponsford & Kinsella, 1992; Spikman et al., 1996; van Zomeren & Brouwer, 1994), it was predicted that differences in the orienting patterns between the two groups would be most evident at shorter cue-target intervals (i.e. 150 ms, 550 ms) but, when given more time to process the cues (i.e. 1000 ms), these differences would diminish. However, the absence of a Group by Cue-Target Interval or a Group by Cue-Type by Cue-Target Interval interaction suggested that the reductions in speed of information processing associated with TBI were not impinging upon the ability of this group to orient attention on the horizontal COAT.

Contrary to predictions, the introduction of a secondary (Language) task had no significant impact upon the orienting patterns of either group on the COAT. In contrast, and consistent with predictions, this dual task condition produced a significant decrement in performance in the TBI group on the Language task. Overall, the small effect sizes reflected the results on the significance tests.

3.5 Study 2

(Vertical presentation – central directional cues)

3.5.1 Background

The majority of studies involving the COAT have presented cues and targets in the horizontal plane (e.g. Cremona-Meteyard et al., 1992; Danckert & Maruff, 1997; Posner et al., 1982, 1984, 1987; Sandson et al., 1988; Wright et al., 1994.). These studies identified specific attentional processes underlying the orienting and movement of attention through the horizontal plane (refer to section 3.2). There have also been a number of studies that have sought to link the orienting of visual attention through the horizontal plane to underlying neuro-anatomical locations. For example, Corbetta, Miezin, Shulman, and Petersen (1993) completed a study using positron emission tomography (PET) and found that, when attention was directed toward the left visual field, there was clear activation in the right superior parietal lobe. However, when attention was directed to the right visual field, the left as well as the right superior parietal lobe became activated (Corbetta et al. 1993). Of interest here is the largely contralateral relationship between the direction of orienting and the hemisphere activated during this orienting. This finding raises questions about how the same neuroanatomical regions could be involved in the orienting of attention within other spatial planes, particularly the vertical plane. It would not be possible, for example, to translate the contralateral relationships seen in the orienting of attention in the horizontal plane to the vertical plane. Thus, different neuroanatomical locations or systems may be responsible for the orienting of attention in the vertical plane; in which case it is possible that there may be differences in the orienting of attention in response to valid, neutral, and invalid cues. Of particular interest was whether the orienting of attention in the vertical plane would reveal differences between TBI and Control groups that were not apparent under horizontal orienting conditions. As a result, it was decided to investigate the orienting of attention in the vertical plane.

To the author's knowledge, there have not been any studies that have investigated the orienting of attention in the vertical plane using a TBI sample. However, there has been one study that has examined the orienting of attention in the vertical plane with a group of patients with a form of Parkinsonism, known as progressive supranuclear palsy (Posner et al., 1982). Interestingly, when the same eccentricities (i.e. degrees) of visual angle were used, Posner et al. (1982) found no differences in RT between the horizontal and vertical COAT conditions.

Using a vertical presentation of the COAT, Study 2 therefore sought to determine whether the findings of Study 1 (horizontal COAT presentation) could be replicated using the same participants.

3.5.2 Aims and Hypotheses

The aim of Study 2 was therefore to examine the orienting of visual attention in the vertical plane in both severe TBI and Control participants. In particular, Study 2 sought to determine whether the findings of Study 1 could be replicated. Divided attention was again assessed by presenting the COAT under both single and dual task conditions. The hypotheses for Study 2 were therefore the same as for Study 1 (refer to pages 71 to 73).

3.5.3 Method

The TBI and Control participants were the same 70 participants who took part in Study 1 (refer to section 3.4.2.1). The tasks presented and procedure were also identical (refer to sections 3.4.2.2 & 3.4.2.3), except that the cues and targets were presented in a vertical, rather than horizontal, plane. The target lights were presented 9 degrees above or below the central fixation point. This eccentricity (i.e. degrees from central fixation point) was the same as that used in the horizontal task. The order of presentation of Study 1 and Study 2 were counterbalanced in a pseudo-random fashion to control for any effects of order. Participants completed the two Studies within one week of each other. The duration of the Study 2 session was approximately 120 minutes.

3.5.4 Results (Study 2)

All data were analysed using SPSS version 11.5 (SPSS, 2002). As in Study 1, finger tapping speed was entered as a covariate into all of the analyses. The COAT performance of the TBI and Control groups was analysed using a repeated measures ANCOVA. A further three ANCOVAs were also performed to examine the specific Benefit, Cost, and Validity effects associated with the different cue types. As with the Study 1 analysis, main and interaction effects that were not specifically related to Benefit, Cost, or Validity effects were not reported in these sections as they were dealt with in the first analysis. Finally, the mean number of errors made on the Language task, under both single and dual task conditions, was analysed using a Group by Task-Type repeated measures ANCOVA.

Matching and Control Variables

As noted previously, an examination of the control variables in Study 1 found significant differences between the two groups in terms of premorbid IQ estimate, gender, and finger tapping speed. However, for the reasons outlined previously (refer to page 80), finger tapping speed was the only covariate to be entered into the analyses within Study 2.

COAT

As with the horizontal task, the vertical COAT was analysed using a four way repeated measures ANCOVA to examine the effects of Group (TBI, Control), Cue-Type (valid, neutral, invalid), Cue-Target Interval (150, 550, 1000 ms), and Task-Type (single, dual) on median RTs. Finger tapping speed was once again entered as a covariate. The mean RTs for the single task conditions are reported in Table 3.5, while the mean reaction times for dual task conditions are reported in Table 3.6.

TABLE 3.5 COAT (vertical presentation - single task) data: means and standard deviations of the median reaction times for each of the cue-target intervals

Cue-Target Interval	Group	Valid Cue	Neutral Cue	Invalid Cue	Benefit (Neutral - Valid RT)	Cost (Invalid - Neutral)	Validity (Invalid - Valid RT)
150 ms	**TBI**	398.7 (99.8)	420.4 (108.6)	412.8 (103.2)	21.7 (21.8)	-7.6 (26.3)	14.1 (20.2)
	Controls	345.1 (62.3)	361.1 (58.5)	372.5 (74.3)	16.0 (13.7)	11.4 (25.4)	27.4 (23.5)
550 ms	**TBI**	349.7 (86.7)	357.7 (84.5)	374.1 (80.8)	8.0 (19.8)	16.4 (79.3)	24.4 (89.0)
	Controls	286.0 (40.0)	308.4 (44.1)	334.3 (53.8)	22.4 (21.3)	25.9 (26.8)	48.3 (33.9)
1000 ms	**TBI**	317.4 (95.2)	335.5 (105.4)	348.9 (106.7)	18.1 (34.9)	13.4 (40.3)	31.4 (33.6)
	Controls	259.3 (41.6)	272.4 (43.0)	290.8 (66.4)	13.1 (15.0)	18.4 (43.5)	31.5 (40.9)

TABLE 3.6 COAT (vertical presentation - dual task) data: means and standard deviations of the median reaction times for each of the cue-target intervals

Cue-Target Interval	Group	Valid Cue	Neutral Cue	Invalid Cue	Benefit (Neutral - Valid RT)	Cost (Invalid - Neutral)	Validity (Invalid - Valid RT)
150 ms	**TBI**	419.9 (63.6)	422.9 (77.2)	429.9 (84.2)	2.9 (77.8)	7.0 (23.4)	9.9 (80.7)
	Controls	353.1 (53.2)	372.3 (57.2)	381.9 (57.3)	19.2 (17.3)	9.6 (21.2)	28.9 (24.5)
550 ms	**TBI**	355.6 (72.6)	360.6 (70.0)	386.3 (78.2)	5.0 (77.7)	25.7 (66.6)	30.7 (48.2)
	Controls	295.0 (44.9)	320.5 (47.9)	348.3 (49.7)	25.5 (16.2)	27.8 (26.2)	53.3 (28.8)
1000 ms	**TBI**	301.0 (104.5)	326.2 (108.6)	333.4 (119.2)	25.2 (33.5)	7.1 (54.6)	32.4 (38.7)
	Controls	260.2 (64.8)	287.7 (53.7)	294.6 (89.6)	27.5 (28.0)	6.9 (58.0)	34.4 (40.4)

The repeated measures ANCOVA of the vertical COAT RT data revealed significant main effects for Group (F(1,67) = 4.22, p = 0.44, partial $\eta^2 = 0.59$), Cue-Type (F(2,134) = 13.38, p = .000, partial $\eta^2 = .166$), and Cue-Target Interval (F(2,134) = 20.25, p = .000, partial $\eta^2 = .232$). There was no main effect for Task-Type (F(1,67) = 2.13, p = .149. partial $\eta^2 = .031$). Inspection of Tables 3.5 and 3.6 reveals that TBI participants were approximately 40 – 60 ms slower than Control participants. However, while this main effect for Group just reached statistical significance, the effect size was relatively small. With respect to the Cue-Type main effect, participants responded fastest to the valid cues and slowest to the invalid cues, with responses to neutral cues being intermediate to these. This pattern of RT in response to the varying Cue-Types is illustrated in Figure 3.6.

The main effect of Cue-Target Interval is illustrated in Figure 3.7. As Cue-Target Intervals increased, RTs decreased, suggesting that both groups were able to take advantage of increased Cue-Target Intervals.

The significant Group by Cue-Type interaction (F(2,134) = 6.53, p = .002, partial $\eta^2 = .089$) revealed that there were significant differences between the groups in terms of the way they oriented their attention to the valid, neutral, and invalid cues. This finding is consistent with Hypothesis 3.1(a), which predicted that there would be a difference between the groups in terms of how they oriented their attention. These differences can be seen in Figure 3.6 where Control participants appear to display a greater Benefit (RT to neutral cue minus RT to valid cue) and Cost (RT to invalid cue minus RT to neutral cue), compared to TBI participants. Thus, in order to examine this Group by Cue-Type interaction more closely, it was necessary to carry out three additional analyses. These analyses are reported in their respective sections below.

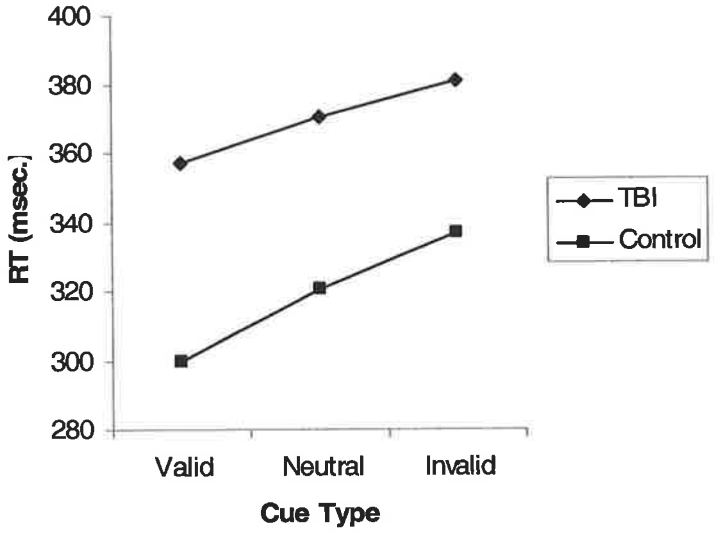
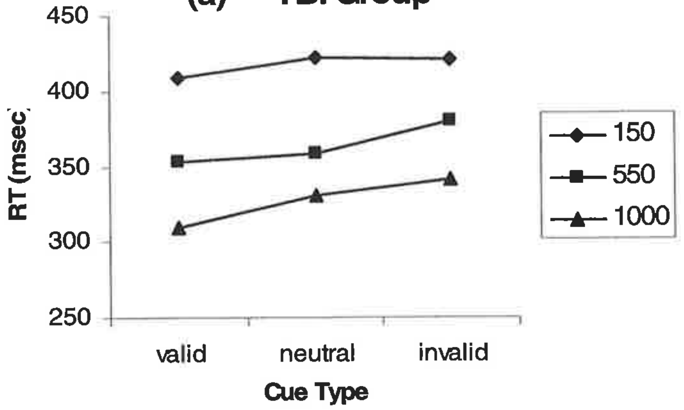


Figure 3.6 Mean of median reaction times, collapsed across the three cue-target intervals (150, 550, 1000ms) and two task types (single, dual), for TBI and Control participants on the COAT (vertical).

(a) TBI Group



(b) Control Group

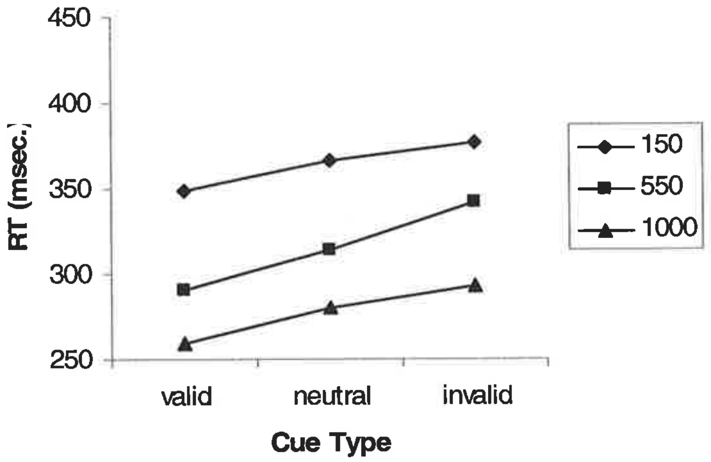


Figure 3.7 Mean of median reaction times for (a) TBI and (b) Control participants under COAT (vertical) conditions, collapsed across the two task types (single, dual).

Benefit

In order to investigate Benefits in response to a valid cue (compared to the neutral cue), a Group (TBI vs controls) by Benefit (Valid RT, Neutral RT) by Cue-Target Interval (150 ms, 550 ms, 1000 ms) by Task Type (single vs dual) repeated measures ANCOVA was performed, with finger tapping speed again entered as a covariate. This analysis revealed a significant main effect for Benefit (F(1,67) = 11.12, p = .001, partial $\eta^2 = .142$), indicating that participants responded faster to a valid than a neutral cue. A significant Group by Benefit interaction ($F(1,67) = 5.33$, $p = .024$, partial $\eta^2 = .074$) revealed that there were group differences in the Benefits obtained from the valid cue, such that the TBI group benefited less from valid cues than did the Controls. This finding was consistent with the prediction that TBI participants would display a reduced Benefit compared to Controls (Hypothesis 3.1(b)).

Cost

The Cost of an invalid cue (compared to a neutral cue) in the vertical COAT was analysed using a Group (TBI, Controls) by Cost (neutral RT, invalid RT) by Cue-Target Interval (150ms, 550ms, 1000ms) by Task-Type (single, dual) repeated measures ANCOVA, with finger tapping speed as a covariate. A significant main effect for Cost ($F(1,67) = 7.24$, $p = .009$, partial $\eta^2 = .097$) was found, indicating that, overall, participants displayed a Cost in RTs to an invalid cue when compared to a neutral cue. However, the interaction between Group and Cost was not significant ($F(1,67) = 3.60$, $p = .062$, partial $\eta^2 = .051$). Thus, this finding did not support Hypothesis 3.1(b), as TBI participants displayed the same Cost in response to invalid cues as did Control participants.

Validity Effect

A Group (TBI, Controls) by Validity (valid RT, invalid RT) by Cue-Target Interval (150 ms, 550 ms, 1000 ms) by Task Type (single, dual) repeated measures ANCOVA (with finger tapping speed as a covariate) found a significant main effect for Validity ($F(1,67) = 17.76$, $p = .000$, partial $\eta^2 = .209$), indicating that participants were orienting their attention in response to valid and invalid cues. There was a significant interaction between Group and Validity ($F(1,67) = 8.67$, $p = .004$, partial $\eta^2 = .115$), indicating that there were differences between the two groups in terms of how they oriented their attention. Tables 3.5 and 3.6 reveal the reduced Validity effect for the TBI group compared to Controls. This reduced Validity effect is consistent with Hypothesis 3.1(b).

Speed of Information Processing

With regard to the impact of speed of information processing upon the orienting of attention, there was a significant Group by Cue-Type by Cue-Target Interval interaction ($F(4,268) = 3.67$, $p = .006$, partial $\eta^2 = .052$). There were also significant Group by Benefit by Cue-Target Interval ($F(2,134) = 5.60$, $p = .005$, partial $\eta^2 = .077$) and Group by Validity by Cue-Target Interval interactions ($F(2,134) = 5.48$, $p = .005$, partial $\eta^2 = .076$). The interaction between Group, Benefit, and Cue-Target Interval was particularly noticeable under dual task conditions where, although the Benefit of the TBI participants was substantially lower than Control participants over the 150 and 550 ms Cue-Target Intervals, at a Cue-Target Interval of 1000 ms the TBI group was able to achieve a Benefit very similar to that of the Controls (refer to Table 3.6). In contrast, the Benefits achieved by the Control participants, although increasing slightly over each of the progressively longer Cue-Target Intervals under dual task conditions, were relatively stable. Similar interaction effects were also evident with regard to Validity. As can be seen in Tables 3.5 and 3.6, there were substantial differences between the two groups at the 150 ms and 550 ms cue-target intervals but, at a cue-target interval of 1000 ms, the Validity effects were similar. These findings were therefore consistent with Hypothesis 3.2 which predicted that deficits in the orienting of attention of the TBI group would be most apparent at shorter Cue-Target Intervals (i.e. 150 ms & 550 ms).

Dual Task (COAT)

An analysis of COAT performance under the dual task conditions revealed a significant Group by Cue-Type by Task-Type interaction ($F(2,134) = 3.38$, $p = .037$, partial $\eta^2 = .048$). However, although this interaction revealed only a relatively small effect size, there was some additional support for this finding in a significant Group by Benefit by Task-Type interaction (F(1,67) = 4.62, p = .035, partial η^2 = .064). Tables 3.5 and 3.6 reveal that while the overall Benefit displayed by TBI and Control participants on the COAT single task condition was very similar, the overall Benefit displayed by the Control group under dual task conditions was more than double that of the TBI group (refer to Tables 3.5 & 3.6). In addition the Group by Cost by Task-Type and Group by Validity by Task-Type interactions did not reach significance. Thus, there was some limited evidence in support of Hypothesis 3.3 which predicted that the introduction of the secondary task would result in a reduced ability of TBI participants to orient their attention in response to valid, neutral, and invalid cues, compared to Controls.

Secondary Task (Phoneme Detection) Performance

The mean number of errors made under both single and dual task conditions is reported in Table 3.7. A Group (TBI, Controls) by Task-Type (Single, Dual) repeated measures ANOVA performed on this data revealed a significant main effect for Group (F(1,68) = 17.65, p = .000, partial η^2 = .206), showing that the TBI participants produced significantly more errors than Control participants. A significant Group by Task-Type interaction (F(1,68) = 10.91, p = .002, partial η^2 = .138) indicates that the TBI group had a greater increase in error rate under dual task conditions. This finding is consistent with Hypothesis 3.4 which predicted that while there would be no difference between TBI and Control participants on the Phoneme Detection Task under single task conditions, under dual task conditions there would be a significant difference between the two groups.

TABLE 3.7 Mean (and SD) number of errors for both single and dual task conditions (vertical presentation)

	Single Task [1]	Dual Task [2]
TBI (n=35)	0.49 (0.87)	2.27 (1.87)
Control (n=35)	0.20 (0.47)	0.86 (0.60)

1. Single task score represents mean number of errors across 6 lists of 20 words.
2. Dual task score represents the mean number of errors across 30 lists of 20 words.

3.5.5 Summary of Results (Study 2)

The results of Study 2 revealed that there were significant differences in how TBI and Control participants oriented their attention in the vertical plane, differences that were highlighted by the significantly reduced Benefit and Validity effects displayed by the TBI group. There was also evidence to suggest that when given less time to process the cues, the ability of TBI participants to orient their attention was reduced. Thus, it appears that the reduced speed of information processing associated with TBI may be impacting upon the ability of TBI participants to orient their attention. When TBI participants were given sufficient time to process the cues (i.e. 1000 ms), they were able to orient their attention in much the same way as Controls.

There was some evidence to suggest that the introduction of the secondary (Language) task produced a deficit in orienting within the TBI group. With regard to the secondary (Language) task, both groups produced low and equivalent error rates under single task conditions but the TBI participants produced significantly more errors than Control participants under dual task conditions. This finding provided evidence of a deficit in divided attention following TBI.

3.6 Discussion (Study 1 and Study 2 Compared)

There were some mixed findings evident when comparing COAT performance across the two studies. Within Study 1 (horizontal COAT), TBI participants displayed a normal orienting pattern in response to each of the cue-types. Furthermore, this normal orienting pattern remained evident when TBI participants were given less time to process the cues, thereby placing a greater load on speed of information processing, and when a secondary (dual) task was introduced. However, Study 2 (vertical COAT) revealed that while the TBI group again displayed a normal orienting pattern at a cue-target interval of 1000 ms, when given less time to process the information (i.e. a cue-target interval of 150 or 550 ms) they displayed deficits in Benefit and Validity effects. There was also evidence to suggest that the introduction of a dual task had a negative impact upon the ability of TBI participants to orient their attention.

The finding of a deficit in the orienting of attention following severe TBI was consistent both with the work of Cremona-Meteyard and colleagues (Cremona-Meteyard et al., 1992; Cremona-Meteyard & Geffen, 1994) and the hypotheses within this chapter. In addition, the finding that this deficit was only apparent when TBI participants were given less time to process the cues is in line with the reports of a number of authors, who have suggested that reduced speed of information processing is a major contributor to attentional deficits following TBI (e.g. Ponsford & Kinsella, 1992; Spikman et al., 1996; van Zomeren & Brouwer, 1994). In addition, the introduction of the dual task within Study 2 significantly reduced the ability of TBI participants to orient their attention to spatial cues, providing evidence of a deficit in divided attention following TBI. The findings in Study 2 are therefore consistent with the Posner model and the pathophysiology of TBI. Give sufficient time to process the cues, TBI participants were able to orient their attention in the same way as Controls. This finding is in line with an intact posterior (parietal) attention system. However, when additional processing demands are placed upon TBI participants, either by increasing the speed at which they are required to process the information, or by introducing a secondary (dual) task, deficits in performance became apparent. These extra processing demands call upon the anterior attention system which, with its location within the frontal lobes, is known to be compromised following severe TBI (Blumbergs, 1977; Gennarelli, 1986; Posner & Raichle, 1994).

Although the findings of Study 2 were in line both with the hypothesis within this thesis, and the model of attention proposed by Posner, the findings of Study 1 were not. The failure to find deficits in orienting on the horizontal COAT (Study 1) may be explained in terms of the level of automaticity developed by TBI participants on this task. This explanation is based both on the work of Posner and Raichle (1994) and the subjective reports of participants within the two Studies. Posner and Raichle (1994) found that as tasks became more automated there was a reduction in activation of the anterior cingulate (Posner & Raichle, 1994). Given that the participants in the current study received two practice blocks of 108 trials, and five blocks of 108 trials under the single task conditions, it is possible that their COAT task performance may have become quite automated, requiring less input from the anterior system (including the anterior cingulate). This notion is consistent with anecdotal accounts of participants who reported greater levels of automaticity as the task proceeded. In addition, a number of participants (both Controls and those with TBI) reported that the introduction of the dual task helped them to stay 'on task' with regard to COAT performance, further reflecting the extent to which the COAT was being processed automatically and the level of demand being placed upon them in the dual task situation. Thus, the increased automaticity may reduce the demands placed upon the compromised anterior attention system of individuals who have sustained a severe TBI. As a result, TBI participants were able to deal more easily with increased processing demands, either because of increased demands upon information processing speed, or the need to divide their attention with the introduction of a secondary task.

This explanation however raises questions about why the TBI participants within the Cremona-Meteyard et al. (1992) study did not appear to benefit from the development of this automaticity and display normal orienting patterns. A closer examination of the Cremona-Meteyard et al. (1992) study reveals a number of factors that may have contributed to the discrepant findings. Firstly, while the mean Benefit of the TBI participants (n = 11) in the Cremona-Meteyard et al. (1992) study was only 1 ms, four of the participants displayed a Benefit in excess of 9 ms, which was the mean Benefit of the TBI participants, at a comparable cue-target interval, in the current study. It is therefore possible that their findings were an artifact of relatively low participant numbers. It is also possible that the failure to find a Benefit may have resulted from an artificially low RT to the neutral cue: the neutral cue may not have been as 'neutral' as intended. As indicated previously, difficulties associated with the interpretation of the neutral cue have been raised by Jonides and Mack (1984) who recommend that, if at all possible, neutral cues should be avoided. If the neutral cue is removed from the analysis of the Cremona-Meteyard data, and the Validity effect is examined (i.e. RTinvalid - RTvalid), their TBI group displayed a Validity effect of 61 ms and the Control group 73 ms. The Validity effect of the TBI group is clearly indicative of a robust orienting of attention, and is of a similar magnitude to the Control group. Of interest, is that this Validity effect is consistent with the one reported by Pavese et al. (1998) for their TBI participants (54 ms), and is greater than the 43 ms reported in the current study. Thus, it appears that the Cremona-Meteyard et al. (1992) study may well be providing some evidence of a robust orienting effect following TBI. A normal orienting pattern following TBI participants on the horizontal COAT is also consistent with the work of Pavese et al. (1998)

and Sandson et al. (1988) who reported that TBI participants were able to orient their attention in the same way as controls.

Despite the differences in findings between the two studies, it is suggested that the results of Study 1 can also be explained in terms of the Posner model. As the horizontal COAT was able to become more automated, there were very limited demands placed upon the anterior attention system, with most processing being carried out by the intact parietal lobe (posterior attention system).

Thus, in comparing the horizontal and vertical presentations of the COAT, it appears that these two presentations may not be as equal as first thought. To the authors knowledge there has only been one study that has directly compared the horizontal and vertical presentation of the COAT (Posner et al., 1982). This study, which included only three participants, each with progressive supranuclear palsy (PSP), found no differences in RT between the horizontal and vertical COAT. However, as reported earlier, Corbetta et al. (1993) has demonstrated a contralateral relationship between the direction of orienting and the hemisphere activated during orienting in the horizontal plane. Such a finding raises questions about whether different neuroanatomical regions are involved in the orienting of attention in the vertical plane. It is also suggested that in the activities of everyday life, the orienting of attention through the horizontal plane is more common than the vertical plane. This is consistent with the accounts of a number of TBI participants within Study 2 who found the vertical COAT to be more difficult than the horizontal COAT. Thus, it is possible that the less common orienting of attention through the vertical plane may place more demands on the attentional system, particularly the anterior attention system, than the orienting of attention through the horizontal plane. As a result, individuals would be more likely to display orienting deficits on the vertical presentation of the COAT, particularly when given less time to process the cues (i.e. shorter cue-target intervals). It is suggested that such a hypothesis would explain the finding of the compromised attentional orienting of TBI participants under single task conditions within Study 2, and that the COAT may represent a more sensitive measure of attentional orienting following severe TBI.

In contrast to the results from the COAT, findings from the secondary (Language) task in Study 1 and Study 2 were in agreement. Although both groups produced equivalent low error rates on the Language (Phoneme Detection) task under single task conditions, under dual task conditions the TBI group produced significantly more errors than Controls. Thus, both Study 1 and Study 2 confirmed the divided attention deficit amongst TBI participants that was predicted in Hypothesis 3.4. The marked reduction in TBI participant performance on the Language task, under dual task conditions, highlights the importance of dual task conditions in the clinical assessment of attention following TBI. It is suggested that the extra load attributed to the dual task condition compromises the attentional function of TBI participants, either because of the reduced amount of attentional resources available, or because of the need to process information at an increased rate. The finding of attentional deficits on the Language task under the dual, compared to the single, task condition is particularly important. Such a finding confirms the claim by Robertson (1995) that dual task conditions are able to ‘unmask’ attentional deficits that would otherwise go undetected under single task conditions. As a result, the inclusion of dual task conditions is critical to the clinical assessment of divided attention in persons with TBI.

The inclusion of a dual task paradigm within the current studies made it possible to examine the interaction of tasks considered to be the domain of the posterior (visual orienting) and anterior attention systems (phoneme detection) outlined within the Posner model (Posner & Petersen, 1990). While the introduction of the dual task produced some evidence of a deficit in attentional orienting within the TBI group, the TBI group also experienced a significant decrement in performance on the phoneme detection task, under dual task conditions. Combining the secondary language task with the COAT therefore assisted in the identification of deficits in the performance of the anterior attention system, in the presence of a preserved posterior attention system, in persons with severe TBI. This finding is consistent with the frontal lobe pathology and intact parietal lobe function, often associated with severe TBI (Blumbergs, 1997). The introduction of the dual (Language) task apparently placed extra demands upon the already compromised frontal lobes. These extra demands probably resulted from the executive/supervisory role played by the anterior attention system in dealing with a dual/divided attention task, and the fact that the Language task is also thought to have its neurophysiological substrates in the frontal lobes (Posner et al., 1988). In contrast, COAT performance, with its neurophysiological substrates in the parietal lobe (Posner et al., 1989), was less affected.

As mentioned previously, the data from Study 1 was originally analysed using the NART-R as a covariate to control for the effects of premorbid IQ (refer to Bate et al., 2001a). However, since the publication of this study, more recent studies have identified some concerns regarding the use of the NART as an estimate of premorbid IQ, particularly within the first 12 months of severe TBI (Freeman et al., 2001; Riley & Simmonds, 2003). In comparing the current analyses with the original analysis of the Study 1 data (Bate et al., 2001a), it was evident that the decision to not include the NART-R as a covariate had no impact in terms of which comparisons were significant.

In summary, despite the discrepancies in the findings between Study 1 and Study 2, the results of both of these studies can be explained within the context of the Posner model, and the reduced speed of information processing associated with TBI. The two studies highlighted the ability of the COAT to examine the effects of speed of information processing upon the orienting of attention. When given sufficient time to process the orienting cues, and with no additional demands upon their attention, TBI participants display a normal orienting pattern, consistent with an intact posterior attention system. However, when more demands are placed upon the orienting of attention, either by (1) reducing the time available process to the cues, or (2) the introduction of a secondary task, the performance of TBI participants declined. Such a decline in COAT performance is consistent with a compromised anterior attention system. This is most evident under the vertical presentation of the COAT, which appears to be a more sensitive measure of attentional orienting. Of particular importance in comparing Studies 1 and 2, was the replication of the finding of a deficit on the Language task under dual task conditions, providing strong evidence for a divided attention deficit following severe TBI, and the need to include dual tasks within the clinical assessment of attention.

3.7 Study 3

3.7.1 Introduction

One of the features of the COAT is that it provides considerable flexibility to vary a number of its parameters; such as, cue-target interval, spatial orientation (i.e. horizontal and vertical), and the *nature* of the cue presented (i.e. central directional cues or peripheral cues presented at the target location). Although Study 1 and Study 2 utilised different cue-target intervals and spatial orientations, the *nature* of the cue presented (i.e. central directional cues) remained the same. However, it is also possible to manipulate the nature of the cue in order to provide additional information regarding whether endogenous (controlled) or exogenous (reflexive) processes are being used to orient attention. The endogenous orienting of attention is a process that is under an individual's direct control and has been described by Danckert et al. (1998) as being directed on the basis of "... ideational, remembered or learned information" (p. 227). Exogenous orienting, on the other hand, is a reflexive process, and is not under the individual's direct control (Posner, 1988; Yantis & Yonides, 1990).

The tasks used in Study 1 and Study 2 only drew upon endogenous orienting processes. That is, the central directional cues presented within these studies required controlled (endogenous) processing in terms of remembering and interpreting the information provided by the central directional arrow cues. As a result, it could be argued that processes other than attention, namely memory and learning, may have contributed to COAT performance in these two studies. Moreover, these studies were not able to assess TBI participants' ability to inhibit exogenous orienting processes. Study 3 therefore sought to investigate the nature of exogenous orienting processes in severe TBI and Control participants, and to make direct comparisons between endogenous and exogenous orienting processes.

The studies that have examined differences between endogenous and exogenous orienting processes have tended to directly compare the performance of participants on peripherally cued tasks with performance on tasks using centrally generated symbolic cues (Posner, 1988; Jonides, 1981; Yantis & Yonides, 1990). The onset of a central symbolic cue (i.e. arrow) requires participants to perform controlled (endogenous) processes in order to direct their attention to the cued location (as was the case in Studies 1 and 2). In contrast, the appearance of a peripheral cue is thought to automatically (reflexively) attract the participant's visual attention to that location. However, Danckert et al. (1998) have suggested that the study of endogenous and exogenous orienting, based solely upon comparing symbolic directional (i.e. centrally presented valid and invalid cues) and peripheral cues, may provide an incomplete picture of the processes involved. They point to the work of Friedrich and colleagues who examined the interaction between endogenous and exogenous orienting processes by manipulating the probability of the correctness of the predictive information provided by the peripheral cue (e.g. Friedrich, Egly, Rafal, & Beck, 1998). For example, at a 50% probability that the target will occur at the cued location, the cue effect size (Validity effect) represents only the effectiveness of the peripheral cue in exogenously (reflexively) orienting the attentional focus (Rafal & Henik, 1994). However, when the probability deviates from 50%, endogenous learned/controlled processes are introduced into the attentional orienting (Rafal & Henik, 1994). With both 50% and 80% probabilities that the target will occur at the cued location (i.e. valid cue), RTs for targets appearing at the cued location are faster than for targets appearing contralateral to the cue (invalid cue) (Maruff & Currie, 1995). However, when there is only a 20% probability that the target will occur at the cued location (valid cue), healthy participants are able to use this predictive information to inhibit the exogenous (reflexive) orienting response toward the cued location and to use endogenous processes to orient toward the opposite location. The ability to inhibit exogenous orienting by endogenous orienting processes is reflected in faster RTs to non-cued (invalid) than cued (valid) locations (Danckert et al., 1998).

The predictive information provided by a cue has been manipulated in a number of studies examining a variety of diagnostic groups. Maruff and Currie (1995), for example, found that patients with Dementia of the Alzheimer's Type (DAT) had difficulty in using endogenous attentional processes to inhibit exogenous shifts of attention. In this study, patients with DAT and Controls were presented with three separate COAT conditions in which the target appeared at the cued location with either an 80%, 50%, or 20% probability. Targets appeared at the same location as the cue (valid cue) or in the contralateral location (invalid cue). Maruff and Currie (1995) found that DAT patients were unable to use endogenous attentional control processes to inhibit reflexive (exogenous) orienting to peripheral cues, even when targets were highly unlikely to appear at the cued location (e.g. at a 20% probability of the cue being valid). This finding was also replicated by Danckert et al. (1998), who further found that this deficit was evident at both short (150 ms) and long (800 ms) cue-target-intervals, suggesting that slower processing alone could not be responsible for these results in their DAT patients. Similar deficits in the endogenous orienting of visual attention have also been reported in patients with schizophrenia (Maruff, Pantelis, Danckert, Smith, & Currie, 1996).

A number of studies have shown that persons who have sustained a TBI are overly susceptible to distraction by inappropriate or irrelevant stimuli (Whyte et al., 1996, 1998). Robertson (1995) has suggested that these difficulties cause individuals to be slaves of their (exogenous) attention. However, studies that have examined the covert orienting of visual attention in participants with TBI have tended to assess only endogenous processing (e.g. Bate, Mathias, & Crawford, 2001a; Pavese et al., 1998; Sandson et al, 1988). There appear to have been no studies that have directly compared endogenous and exogenous orienting processes in individuals with severe TBI.

3.7.2 Aims and Hypotheses

The aim of Study 3 was therefore to directly compare the endogenous and exogenous orienting processes of both severe TBI and Control participants. Severe TBI and Control groups were administered a peripherally cued COAT in which the probability of the cue being valid was either 80% (measuring exogenous processes) or 20% (measuring endogenous processes).

Hypothesis 3.7

It was hypothesised that TBI participants would both display a deficit in the endogenous orienting of attention. Thus, while TBI and Control groups would display similar Validity effects in response to an 80% probability of the cue being valid, when the probability of the cue being valid is 20%, TBI participants would be unable to use endogenous attentional processes to override exogenous processes. Thus, it was predicted that there would be a significant Group (TBI, Controls) by Validity (invalid cue, valid cue) by Task-Type (endogenous, exogenous) interaction when an analysis of variance (ANOVA) was performed.

3.7.3 Method

3.7.3.1 Participants

Eleven participants[1] with severe non-penetrating TBIs (9 males, 2 females) and 11 Controls (6 males, 5 females) took part in this study. TBI participants were recruited from consecutive admissions to an outpatient community rehabilitation program. The TBI group in this study represented a different group of participants to those who participated in Study 1 and Study 2. Severity of injury was classified by the lowest recorded Glasgow Coma Scale in the first 24 hours post injury [GCS ≤ 8] and/or a period of Post Traumatic Amnesia (PTA) > 24 hours, as measured by the Julia Farr Post-Traumatic Amnesia Scale (Forrester & Geffen, 1995). Where PTA scores were not available, retrospective reports were used to estimate PTA.

The 11 Control participants were recruited from the general community and were individually matched as closely as possible to the TBI sample on the basis of age, estimated premorbid IQ, and years of education. Demographic and clinical screening data for both groups are displayed in Table 3.9. Participants with a history of major psychiatric disorder, intellectual disability, or other neurological disorders were excluded from the study, as were those who had a hemiplegia of their dominant hand, whose native language was not English, or who had a documented history of substance abuse.

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[1] While this sample may be considered small, it is in keeping with other COAT studies that also have relatively small sample sizes (e.g. Cremona-Meteyard et al., 1992; Danckert & Maruff, 1997; Danckert et al., 1998; Wright et al., 1990). To a large extent the sample size was dictated by the relatively small number of participants who were available due to the small population base of Adelaide. However, by calculating effect sizes, it is possible to determine the extent to which the groups differ, independently of sample size.

TBI participants were also excluded from the study if they displayed symptoms of hemi-neglect or if they suffered any visual problems (e.g. field loss, diplopia), as assessed by either the rehabilitation or opthalmological medical consultant.

TABLE 3.8 Means and standard deviations for demographic and clinical screening data for the TBI and Control groups

	TBI *(n=11)*		***Controls*** *(n=11)*	
Age (years)	34.0	(10.5)	27.5	(10.4)
Education (years)	12.4	(2.5)	14.1	(1.6)
Premorbid IQ Estimate	98.3	(11.7)	99.2	(8.9)
Finger Tapping Speed	42.8	(8.7)	50.2	(3.9)
GCS	4.1	(1.5)		
PTA (days)	42.1	(19.5)		
Time Since Injury (days)	1418.9	(1227.4)		

GCS = Glasgow Coma Scale; PTA = Post-Traumatic Amnesia.

3.7.3.2 Tasks

Covert Orientating of Attention Task (COAT)

This task was based upon the COAT task originally devised by Posner and colleagues (Posner, 1980; Posner et al, 1984). Participants were seated at a table in a dimmed room in front of a 15 inch (diagonal measurement) monitor, controlled by an IBM compatible computer. The outline of three squares in the horizontal plane, each subtending 4 degrees of visual angle, remained present on the computer screen for the duration of the experiment (refer to Figure 3.8). Participants were required to depress a micro-switch as quickly as possible, with the index finger of their preferred hand, in response to the presentation of one of two peripheral targets. These targets took the form of a red square, subtending 2.5 degrees of visual angle, and were located at the centre of one of the two peripheral squares, 9 degrees to the left or right from fixation. The central fixation point was represented by a red cross (+), located in the centre of the middle square, and subtending one degree of visual angle. This cross remained present for the duration of the experiment.

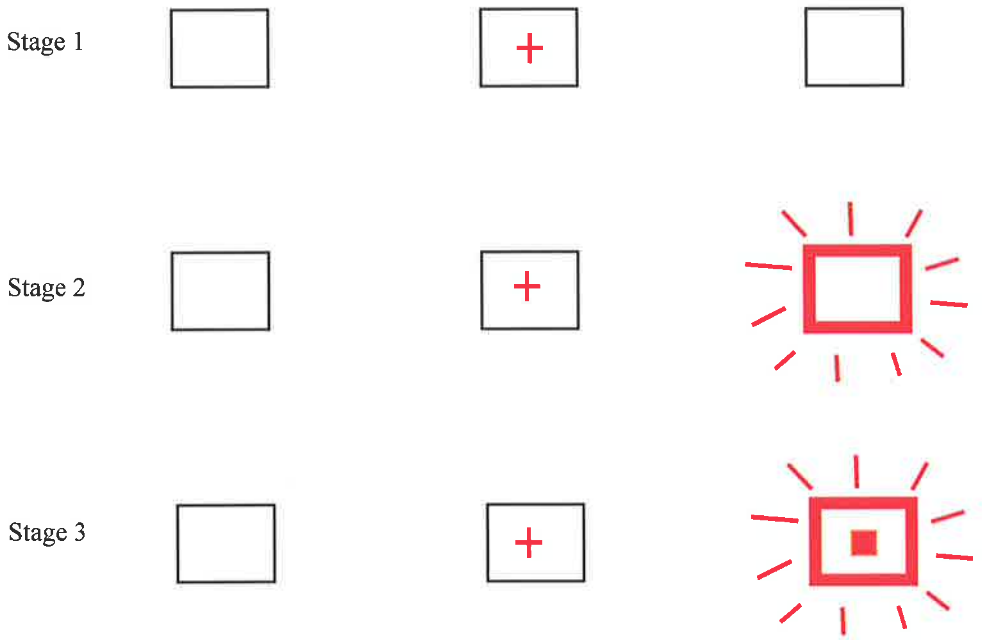

Figure 3.8: Schematic diagram of the stages involved in the covert orienting of attention task, valid cue

Cues were provided by doubling the luminance of the outline colour of one of the peripheral squares (Stage 2, Figure 3.8). The interior of the squares remained blank with a black background. The cues were either valid (target occurred at the peripherally cued location), invalid (target occurred at the location contralateral to the peripheral cue), or neutral (a doubling of the luminance of the outline of the central square, but not giving any predictive information). The design of these cues was consistent with those used in previous studies

(Danckert et al., 1998; Maruff and Currie, 1995; Maruff et al., 1996). The cues remained present during target presentation, and both cue and target were terminated either by a participant's response or 900 ms after the target onset. A chin rest was mounted on the table to ensure that the participant's nasion remained a constant 100 cm from the point of fixation, thus ensuring that the visual angle was preserved.

Two COAT conditions were administered, with 80% and 20% probability of the target being at the cued location. Visual cues were presented in the peripheral location either 150 or 800 ms before the onset of the target, the order of these intervals being randomised in order to avoid anticipatory responses. These intervals were chosen to examine the impact of information processing speed upon task performance and were based upon the intervals used by a number of other studies that have utilised this task (e.g. Danckert & Maruff, 1997; Pavese et al., 1998). The inter-trial interval was fixed at 1000 ms and, to be accepted, responses had to be made between 100 and 900 ms following target onset. Responses either side of these parameters were assumed to indicate anticipatory responses or lapses of attention and were removed from further analysis. In each condition and for each cue type (i.e. valid, neutral, invalid), an equal number of targets were presented to the left and right visual fields in a pseudorandom order. Likewise, the two different cue-target intervals were distributed evenly across cue conditions and visual fields.

In order to ensure that only the covert orienting of attention was being measured, independent of eye movement, both horizontal and vertical eye movements were recorded using four 8mm silver cup electrodes located on the outer canthi of both eyes, and the upper and lower orbit of the left eye. The EOG amplifier was set to have a gain of 10,000 times and bandpass filter (6db / octave) settings of 0.03 Hz to 30 Hz at -3db. All inter-electrode impedences were maintained below 5 kOhms throughout the study. Trials were not included in data collection if eye movements exceeded the rejection threshold of 100 microvolts. Task presentation and data collection was controlled by a PC-486 with purpose written software. The switch used to register each button press was a CNK fast action toggle change over with a force to actuate of 33 to 35 grams and a plunger travel of 0.45 mm.

Finger Tapping Test (Spreen & Strauss, 1991)

This test was included once again to control for the effects of deficits in motor speed that may contribute to reduced RTs on the COAT task. The reader is referred to page 79 of this chapter for a detailed description of this measure

Measures of Injury Severity.

Both the Glasgow Coma Scale (Teasdale & Jennett, 1974) and the Julia Farr Post-Traumatic Amnesia Scale (JF-PTA) (Forrester & Geffen, 1995) were used to determine injury severity (refer to pages 3 to 5 for a description of these measures).

National Adult Reading Test - Revised (UK)

The National Adult Reading Test - Revised (NART-R UK) was administered in order to determine whether there were any premorbid IQ differences between the two groups. However, since the collection of the Study 3 data, questions have been raised regarding the validity of the NART, particularly with regard to its use in estimating premorbid IQ in severe TBI participants who are within 12 months of their injury (e.g. Freeman et al., 2001; Riley & Simmonds, 2003). Thus it was decided not to use the NART-R as a covariate should any significant differences on the NART-R between the groups be evident. As can be seen in Table 3.8, there were no significant differences between the TBI and Control groups on the NART-R.

3.7.3.3 Procedure

All data was gathered in a single testing session. The NART-R and Finger Tapping Test were the first tasks to be administered, followed by the two COAT conditions (i.e. 80% target-at-cue, 20% target-at-cue). The first of the two COAT conditions was completed, followed by a rest period of 15 minutes, and then the second COAT condition. The order of presentation of the two conditions was counterbalanced to control for any effects of order. Each COAT condition consisted of two blocks of 120 trials with a two minute break between each block. The 80% target-at-cue probability block comprised 80 valid, 20 invalid and 20 neutral cues, with the 20% target-at-cue probability block including 20 valid, 80 invalid and 20 neutral cues. The total session time was approximately 100 minutes.

3.7.4 Results

As in Study 1 and Study 2, scores on the matching and control variables were analysed first to determine whether there were any significant differences between the two groups. Where significant differences were found, these variables were entered as covariates into all subsequent analysis. The COAT performance of the TBI and Control groups was then compared using an analysis of covariance (ANCOVA). Consistent with other studies that have used this COAT design (e.g. Danckert et al., 1998; Maruff & Currie, 1995), Validity effects (invalid RT minus valid RT) were also calculated. A second ANCOVA was then performed to examine these Validity effects.

3.7.4.1 Statistical Analyses

Matching and Control Variables

While the TBI and Control groups were successfully matched for age, years of education, and estimated premorbid IQ estimate (refer to Table 3.8), there were significant differences between the groups on finger tapping speed (F(1,20) = 6.49, p = .019, partial η^2 = .245). As a result, finger tapping speed (preferred hand) was entered as a covariate into all subsequent analysis.

COAT

The COAT data was analysed using a four way repeated measures ANCOVA to examine the effects of Group (TBI, Control), Cue-Type (valid, neutral, invalid), Cue-Target Interval (150, 800 ms), and Task-Type (endogenous, exogenous). Finger tapping speed was entered as a covariate. Reaction times for the exogenous orienting task are reported in Table 3.10, while reaction times for the endogenous orienting task are reported in Table 3.11. The repeated measures ANCOVA revealed a significant main effect for Group (F(1,19) = 4.52, p = .047, partial η^2 = .192), indicating that the TBI group was slower than the Control group. There were no significant interactions.

A second repeated measures ANCOVA was then performed to specifically examine Validity effects. As with the previous analysis, this four way repeated measures Group (TBI, Controls) by Validity (invalid cue, valid cue) by Cue-Target Interval (150 ms, 800 ms) by Task-Type (endogenous, exogenous) ANCOVA revealed a significant main effect for Group (F(1,19) = 4.67, p = .044, partial η^2 = .197) and no significant interactions. Thus, while the significant main effect for Group indicates that the overall RTs of TBI participants were significantly slower than Controls, the absence of any other significant interaction effects suggest that the exogenous and endogenous orienting processes of TBI participants was similar to that of Controls. Hypothesis 3.7 was therefore not supported.

While the current analysis failed to find any significant interaction effects, the Group by Validity by Task Type (F(1,19) = 1.46, p = .241, partial η^2 = .071) and Group by Validity by

Task Type by CTI (F(1,19) = 1.91, p = .183, partial $\eta^2 = .091$) interactions did reveal medium effect sizes, reflecting the group differences seen in Tables 3.9 and 3.10. Of particular interest is the difference between the Validity effects of the TBI and Control groups on the exogenous orienting COAT (refer to Table 3.9).

TABLE 3.9 COAT exogenous orienting task – means and standard deviations of the median reaction times for each of the cue-types and cue-target intervals

Cue-Target Interval	Group	Valid Cue	Neutral Cue	Invalid Cue	Validity Effect
150 ms	**TBI**	429.1 (75.7)	465.0 (96.4)	469.3 (93.3)	40.2 (36.5)
	Control	342.5 (66.7)	368.0 (74.5)	378.4 (76.8)	35.9 (19.1)
800 ms	**TBI**	330.0 (61.3)	343.9 (66.8)	328.9 (104.4)	-1.1 (61.0)
	Control	269.1 (72.7)	290.5 (78.9)	306.1 (84.2)	37.0 (31.5)

Both groups produced similar Validity effects at a cue-target interval of 150 ms but, at a cue-target interval of 800 ms, the TBI group displayed a negative Validity effect (n.b. a negative Validity effect is the result of RTs to invalid cues being faster than RTs to valid cues). In contrast, the Validity effect of the Control group remained at a level similar to their performance at a cue-target interval of 150 ms. This finding is contrary to the results of Study 2, as it suggests that when given more time to process the cues, the performance of the TBI group declined. In addition, neither the TBI or Control groups produced a negative Validity effect at a 150 ms cue-target interval under endogenous orienting conditions refer to Table 3.10), suggesting that they were still orienting their attention exogenously (reflexively).

TABLE 3.10 COAT endogenous orienting task – means and standard deviations of the median reaction times for each of the cue-types and cue-target intervals

Cue-Target Interval	Group	Valid Cue	Neutral Cue	Invalid Cue	Validity Effect
150 ms	TBI	417.0 (56.6)	424.1 (42.3)	433.4 (62.1)	16.4 (45.7)
	Control	328.2 (65.0)	340.0 (65.0)	336.8 (64.7)	8.6 (14.8)
800 ms	TBI	346.1 (64.7)	298.4 (71.0)	298.9 (62.3)	-47.3 (40.9)
	Control	296.8 (105.4)	266.8 (65.2)	241.6 (77.9)	-55.3 (43.4)

3.7.5 Discussion

The main aim of Study 3 was to determine whether TBI participants were able to use endogenous orienting processes to inhibit and override exogenous (reflexive) ones. Previous studies of attention, using different experimental paradigms, have revealed that severe TBI sufferers have difficulty in inhibiting the movement of their attention to inappropriate or irrelevant stimuli (Whyte et al., 1996, Whyte et al., 1998). As a result, it was hypothesised that when endogenous and exogenous orienting processes were compared, TBI participants would be unable to use endogenous attentional processes to inhibit exogenous ones.

Contrary to Hypothesis 3.7, the results of Study 3 revealed that TBI participants were able to use endogenous attentional processes to inhibit exogenous ones. This was particularly evident at a cue-target interval of 800 ms (refer to Table 3.10), where both groups produced negative Validity effects, indicating that they were able to inhibit reflexive orienting processes and orient their attention in an endogenous (controlled) manner. However, it is suggested that some caution should be taken when interpreting these results given the relatively small participant numbers in each group (N=11). While this sample size is consistent with a number of other published studies that have compared endogenous and exogenous orienting in other diagnostic groups (e.g. Danckert & Maruff, 1997; Danckert et al., 1998; Maruff & Currie, 1995; Maruff et al., 1999), it resulted in limited statistical power.

Although the analysis of the Study 3 data failed to find any significant interaction effects, there were a number of interesting findings that warrant further discussion. In particular, it can be seen from Table 3.9 that, although at a cue-target interval of 150 ms on the exogenous COAT, TBI and Control participants produced equivalent Validity effects, at a cue-target interval of 800 ms, the TBI group failed to produce a Validity effect. In contrast, there was no difference in the Validity effect between these two cue-target intervals for the Control group.

While this finding is contrary to what was expected, it is possible that some TBI participants became confused about the probability of the target appearing at the cued location. It is possible that this confusion may have come about by the fact that the administration of the two COAT conditions (i.e. exogenous and endogenous) were counterbalanced for order. As a result, some participants received the endogenous COAT first. It is possible that, on the subsequent administration of the exogenous COAT and at the longer cue-target interval of 800 ms, they may have reverted to the probability of the endogenous COAT. Thus, it may be that at the shorter cue-target interval TBI participants oriented their attention reflexively but, when given more time to process the cue, they recalled the probability of cue accuracy from the previous endogenous task and oriented their attention accordingly. It is suggested that any future administration of these tasks should include more precise instructions regarding the differences in the probabilities between the endogenous and exogenous COAT presentations, and that the participant's understanding of these differences be assessed prior to the commencement of each task.

A further finding of note was that, although not reaching significance, both groups revealed an inability to inhibit reflexive orienting at a short cue-target interval. While the Validity effects were not as large as under the exogenous COAT, suggesting the existence of some endogenous orienting, at this short cue-target interval both groups did not have sufficient time to inhibit and override the outcomes of reflexive processes. Perhaps attention is first oriented exogenously but is then modified by endogenous processes. In addition, the TBI group produced a Validity effect twice as large as the Control group, suggesting that TBI participants, in particular, needed more time in order to utilise endogenous orienting processes. However, given more time to process the cues both groups produced robust negative Validity effects, suggesting that they were both able to endogenously orient their attention in a similar fashion. This study therefore needs to be replicated with a larger sample in order to determine whether these interactions are significant. Although the results of Study 3 failed to confirm the hypothesis within the current study, they did confirm the findings from Studies 1 and 2; namely that TBI participants orient their attention in much the same way as Controls, only more slowly.

3.8 Overall Conclusions

This Chapter examined the performance of TBI and Control participants using a number of variations of the COAT. While there was some evidence that the TBI group displayed deficits in their ability to orient their attention in response to certain visual cues, this deficit was only apparent at short cue-target intervals. When given more time to process these cues, TBI participants oriented their attention in much the same way as Controls. This finding is consistent with a number of studies that have concluded that the deficits displayed by TBI participants on attentional tasks can be attributed to deficits in speed of information processing rather than specific attentional processes (e.g. Ponsford & Kinsella, 1992; Spikman et al., 1996).

There was some evidence that, as hypothesised, the introduction of a secondary (Language) task had a greater impact on the attentional orienting processes of the TBI group. The TBI group also displayed a significant deficit on the Language task under dual task conditions, indicating a reduced ability to perform language tasks when having to divide attention. This finding was replicated in both the horizontal and vertical COAT conditions, providing further confirmation for this finding and highlighting the importance of dual task paradigms in the assessment of attention. Contrary to expectations, TBI participants were able to inhibit reflexive processes and orient their attention in a controlled (endogenous) manner on the COAT.

Thus, the ability to orient attention has been found to be preserved following severe TBI. This finding is consistent with the underlying neuropathology associated with TBI, with the neuroanatomical substrates of attentional orienting being located within the relatively preserved parietal lobes.

Although the COAT has proven to be an important tool in furthering our understanding of the nature of attentional function following TBI, it is not currently used within clinical practice. The next chapter therefore focuses upon a number of clinical measures that have been used to assess attentional function following severe TBI, with a particular emphasis on the Test of Everyday Attention (Robertson et al., 1994).

CHAPTER 4

THE NEUROPSYCHOLOGICAL ASSESSMENT OF ATTENTION

4.1 Introduction

Attentional deficits have been identified as one of the most pervasive cognitive impairments within a number of diagnostic groups, with relatively minor attentional deficits significantly reducing the individual's capacity for new learning (Kinsella et al., 1997). Thus, a comprehensive assessment of attention is important, in order to identify attentional problems and to establish a baseline against which to measure recovery and the effectiveness of rehabilitation programs. However, as discussed in Chapter 2, problems with the definition of attention and its underlying theoretical constructs, have limited the development of assessment procedures. As a result, the assessment of attention has not developed to the same extent as the assessment of other cognitive processes such as memory, learning, and language (van Zomeren & Brouwer, 1992). In fact, many of the psychometric measures that are used in the assessment of attention have been 'borrowed' from more broad-based measures of intellectual functioning (Levin & Benton, 1984).

The current chapter examines a range of measures that purport to assess the components of attention that were outlined in Chapter 2, together with their limitations. Studies that have examined the performance of severe TBI sufferers on conventional measures, in addition to the more recently developed Test of Everyday Attention (TEA), are then reviewed. Finally, a number of hypotheses are posed in relation to conventional neuropsychological measures of attention, the TEA, and a questionnaire measure of attentional behaviour. These hypotheses are then tested in Study 4, which forms the basis of the remainder of this Chapter.

4.2 The Assessment of Attention

As discussed in Chapter 2, attention is comprised of a number of components, including arousal, the orienting of attention, hemi-attention/neglect, focussed attention, divided attention, sustained attention, and supervisory attentional control. While orienting and hemi-attention are thought to be under the control of the posterior attentional network (i.e. posterior parietal lobes), focussed, divided, sustained, and supervisory attention are subsumed under the anterior attentional system (i.e. frontal lobes) (Posner & Petersen, 1990; Posner & Raichle, 1994). Given the existence of these attentional components and networks, it follows that a comprehensive assessment of attention requires the use of a variety of measures (van Zomeren & Brouwer, 1994). This section outlines a number of the measures that are thought to assess these different components of attention.

4.2.1 Arousal

As mentioned in Chapter 2, the terms 'arousal' and 'alertness' are often used interchangeably to refer to an individual's general receptivity to stimulation (Posner, 1975). While relatively severe disturbances in alertness and arousal are assessed by the Glasgow Coma Scale (GCS) (Teasdale & Jennett, 1974), clinicians are often required to carry out an assessment of arousal at later post-acute stages of recovery following TBI.

Changes in alertness are either *phasic* or *tonic* in nature. The assessment of *phasic* changes has been carried out by comparing reaction times (RT) with, and without, a warning signal (van Zomeren & Brouwer, 1992). However, the equipment needed to carry out such an assessment is rarely available in clinical practice, nor are the procedures standardised. *Tonic* changes in alertness refer to the slower involuntary changes that occur as a result of physiological changes within the individual (van Zomeren & Brouwer, 1994). One example of such a change is the variation in alertness in response to circadian rhythms, where levels in alertness are determined by the gradual changes in deep body temperature over a 24 hour period (van Zomeren & Brouwer, 1994). Not surprisingly, the assessment of *tonic* change is also very difficult to carry out in clinical settings, as it requires the monitoring of long registration periods with relatively high technology equipment (van Zomeren & Brouwer, 1994).

While quantitative information regarding alertness is rarely available to the clinician, van Zomeren and Brouwer (1994) suggest that behavioural observation of the patient is, in most instances, able to provide sufficient information. In addition, there are a number of behavioural rating scales (e.g. The Neurobehavioural Rating Scale; The Rating Scale of Attentional Behaviour) that obtain information from the clinician, the patient, or a close relative to assess alertness (Levin et al., 1987; Ponsford & Kinsella, 1991).

4.2.2 Hemi-attention

Disorders of hemi-attention are typically referred to as either neglect or hemi-inattention. This disorder of attention refers to the tendency of an individual to neglect one half of their environment or body (Halligan & Robertson, 1992), with left sided neglect being the most common (Denes et al., 1992). Such a disturbance can often be seen in an individual's day-to-day activities as they may bump into objects on their left side or may fail to notice material on the left half of the table during a testing session (van Zomeren & Brouwer, 1994). There are a number of formal assessment procedures that are used for detecting neglect. Tasks involving the copying of various designs are often used. For example, the Rey-Osterrieth Figure (Corwin & Bylsma, 1993), although not designed specifically as a test of neglect, may indicate neglect if a patient fails to copy the left half of the figure. Letter or digit cancellation tasks are also useful in the assessment of hemi-neglect (Binder, Marshall, Lazar, Benjamin, & Mohr, 1992), as is the line bisection task (Diller et al., 1974), where the patient is required to bisect lines placed in different positions on a page. Finally, the Behavioural Inattention Test (Wilson, Cockburn, & Halligan, 1987) is a battery of 14 sub-tests designed specifically to assess hemi-attention. This test incorporates some existing measures of hemi-attention (e.g. line bisection, cancellation tasks), as well as a number of sub-tests that involve more naturalistic/ecologically valid test items.

4.2.3 Orienting

The orienting of attention was discussed in detail in Chapter 3 and, while it is thought to represent the most fundamental of all attentional processes (Posner et al., 1982), the need for relatively sophisticated equipment and lack of standardised norms generally precludes it from being measured in clinical settings. This is unfortunate, as the ability to identify deficits in the orienting of attention using the COAT may have significant clinical relevance. Given the increasing availability of computer equipment in clinical settings, it is possible that the software programs that are used in experimental laboratories will be adapted for use in clinical practice.

4.2.4 Selective Attention (Focussed and Divided Attention)

Our capacity to process incoming stimuli is limited, forcing us to selectively attend to information either by focusing our attention on one stimuli or dividing it between multiple stimuli.

4.2.4.1 Focussed Attention

Focussed attention refers to the ability to respond to specific visual, auditory, or tactile stimuli (Sohlberg & Mateer, 1989). Experimental paradigms have typically investigated focussed attention by manipulating distractors, as is the case with dichotic listening tasks, where two sources of information are presented with the instruction to focus on only one of them (e.g.

Cherry, 1958; Treisman, 1964). Although dichotic listening tasks provide a well controlled methodology for studying divided attention (Cohen et al., 1993), difficulties in accessing the necessary equipment and a lack of standardised norms, have meant that these tasks are rarely used in clinical practice.

One of the most widely used tasks in the clinical assessment of focussed attention is the Stroop Colour Word test (Stroop, 1935). While there are a number of versions of this test in common use (e.g. Golden, 1978; Trenerry, Crosson, DeBoe, & Leber, 1989), it basically comprises three parts: (1) reading colour names that are printed in black ink; (2) naming coloured sequences of four Xs (e.g. XXXX or XXXX); and (3) naming the colours of printed words that are printed in a conflicting colour (e.g. GREEN or RED) (Golden, 1978). The difference in performance between the second and third sub-tests provides a measure of interference (Batchelor, Harvey, & Bryant, 1995), with strong interference effects suggesting difficulties in the ability to focus attention.

Interference effects have not always been found in groups where attentional problems are commonly reported, such as TBI (Stuss et al., 1985), leading Bohnen et al. (1992) to devise a fourth sub-test for the Stroop in order to increase its sensitivity. This additional sub-test is based upon the third sub-test of the original Stroop. The only difference with the stimulus sheet used in the fourth sub-test is that rectangles are drawn around 20 of the words. As with the third sub-test, participants are instructed to name the colour of the printed word. However, when they come to a word within a rectangle, they are required to read the word rather than name the colour in which it is printed. The interference effect is calculated by subtracting scores on this sub-test from the second sub-test.

Another task that is often used in the assessment of focussed attention is the Ruff 2s and 7s Selective Attention test (Ruff, Evans, & Light, 1986). This task was originally designed to examine differences in performance in response to the occurrence of obvious distractors, compared to less obvious distractors (Lezak, 1995). The test is basically a letter cancellation task consisting of 20 three-line blocks of characters. Ten of these blocks consist of alphabetic characters, while the other ten are made up of digits. The task of selecting 2s and 7s from amongst alphabetic characters (obvious distractors) is thought to be a more automatic task than selecting from amongst other digits (less obvious distractors), which is regarded as a more effortful or controlled task.

Healthy individuals have been found to produce significantly less correct responses in the controlled (digit-digit) condition than in the automatic (digit-letter) condition on the Ruff 2s and 7s Selective Attention Test (Ruff et al., 1986). In clinical populations, individuals with anterior lesions have displayed a greater discrepancy in accuracy between automatic and controlled tasks than patients with posterior lesions (Ruff et al., 1992). Such a finding is consistent with the hypothesis that controlled processing is mediated by the frontal lobes (Shallice, 1982), with damage to the frontal lobes resulting in a reduction in performance on controlled processing tasks. In contrast, automatic processing, which is thought to be under the control of posterior regions of the brain, remains unaffected (Ruff et al., 1992).

4.2.4.2 Divided Attention

Divided attention includes the ability to respond simultaneously to multiple tasks (Park et al., 1999). Although originally devised as a measure of speed of information processing, the Paced Auditory Serial Addition Task (PASAT; Gronwall & Sampson, 1974) has been used widely as a test of divided attention (Spreen & Strauss, 1998). The PASAT involves listening to a random series of single digit numbers presented by means of a tape recorder. The subject is instructed to add each number to the one that came before it (the second digit is added to the first, the third to the second, etc.). The subject is therefore required to hold in a short term store each number that is presented, add it to the previous number, respond verbally with the answer, disregard ('forget') the answer, add the next number presented to the previous number, and so on. The task is made progressively more difficult by reducing the time interval between the presentation of the digits.

Another test that is often used to assess divided attention is the Trail Making Test. This test, which was originally devised as part of the Army Individual Test Battery (1944; cited in Lezak, 1995), has now been included in the Halstead-Reitan Battery (Reitan & Wolfson, 1993). The test is administered in two parts. In Part A, the participant is required to draw lines connecting consecutively numbered circles on a sheet of paper. Part B includes circles containing both numbers and letters of the alphabet. Participants are required to join circles, alternating between numbers and letters. The time taken to complete the task is recorded. It is argued that Trails B taps into divided attention by loading the participant's working memory with the task of keeping track of both the numeric and alphabetic sequences (Kinsella, 1998).

While the PASAT and Trail Making Test have been widely used in clinical settings to assess divided attention (as they both require parallel or alternating processing), the dual task paradigm has provided the most direct means of assessing this aspect of attention in experimental settings (e.g. Park et al., 1999; Posner et al., 1994). Unfortunately, there are very few dual task measures available to the clinician.

4.2.5 Sustained Attention

Sustained attention, which is the ability to maintain a consistent behavioural response during continuous and repetitive activity (Sohlberg & Mateer, 1989), is typically assessed by vigilance tasks. These tasks involve the sequential presentation of stimuli (either auditory or visual) over an extended period of time (e.g. five minutes), with the subject being required to indicate whenever a certain target stimulus appears. The simplest form of vigilance task involves the presentation of only one target form (Lezak, 1995). The Ruff 2's and 7's Selective Attention Test is one such example and, although it is widely used as a test of focussed attention (by examining the interference effects of two forms of distractors), the overall score from this test is thought to provide a measure of sustained attention. There are also a number of other cancellation tasks that are available to the clinician (eg. Brickenkamp, 1981; Diller et al., 1974; Haligan, Cockburn, & Wilson, 1991; Weinberg & Diller, 1968). The Star Cancellation task, for example, requires participants to cancel out small stars which are embedded within a jumbled array of letters, words, and both small and large stars (Halligan et al., 1991). More complex versions of sustained attention tasks require the participant to respond only when the target is preceded by a specific item, such as having to cancel out the letter B only when it follows D (Lezak, 1995).

One test that was designed specifically to assess sustained attention is the Continuous Performance Test of Rosvold, Mirsky, Sarason, Bransome, and Beck (1956). Although a number of versions of this test have been produced, the basic paradigm involves assessing sustained attention in response to infrequently occurring stimuli (Riccio, Reynolds, Lowe, & Moore, 2002). In the original task, designed by Rosvold et al. (1956), letters were presented visually one at a time, with 920 ms between each presentation. Participants were required to press a lever whenever the letter 'X' appeared, and to inhibit responding to the other letters (Rosvold et al., 1956). The key demand of this test is task duration, as the information load is relatively low (Cohen et al., 1993). Rosvold et al. (1956) also introduced a variation of this task in which participants were instructed to again respond to the letter 'X' but only if it had been preceded by the letter 'A'. In recent years, the Continuous Performance Test has been further modified to control for various parameters, including inter-stimulus and intra-stimulus interval, number of trials, and type of stimulus (Cohen et al., 1993).

Another task sensitive to the ability to sustain attention is the Symbol Digit Modalities Test (SDMT; Smith, 1982). This task involves a higher level of task demand than the Continuous Performance Test or cancellation tasks. Participants are required to convert a series of symbols to numbers using a key. Oral presentation of the test is also possible, thereby reducing the confound of hand writing speed. Ruff et al. (1992) suggest that the Digit Symbol subtest of the WAIS-R (the test upon which the SDMT is based) is the most commonly used test of attention in clinical practice. The SDMT has been found to be sensitive to a wide range of diagnostic conditions including dementia and depression (Pfeffer et al., 1981), Huntington's disease (Starkstein et al., 1988), and severe TBI (Ponsford & Kinsella, 1992). However, as the duration of the test is only 90 seconds, its ability to assess prolonged sustained attention is significantly limited (Ruff et al., 1992). It has been suggested, for example, that a five minute period represents the lower time limit for adequately assessing sustained attention (Broadbent, 1971; Parasuraman & Davies, 1984). In addition, visuo-perceptual, orthographic, and memory abilities may also influence SDMT test performance (Lezak, 1983; Shum, McFarland, & Bain, 1990).

4.2.6 Supervisory Attentional Control

The concept of Supervisory Attentional Control is one of the more recently introduced concepts to the clinical assessment of attention. Supervisory Attentional Control refers to the control strategies that are employed by an individual to allocate attentional processing capacity, and is closely linked to the 'executive functions' described by Luria (1966) and Lezak (1982). In the assessment situation, qualitative information obtained from observing the patients' flexibility and the way in which they allocate their attentional resources to the various tasks at hand, are both indicators of Supervisory Attentional Control activity (van Zomeren & Brouwer, 1992). In order to formally assess the concept of Supervisory Attentional Control, Shallice (1982; 1988) developed the 'Tower of London' task, which was based upon the oriental puzzle, the Tower of Hanoi. This task involves giving participants a pattern that they must copy by arranging three coloured beads on three vertical sticks of decreasing length. As the solution to the puzzle requires the participant to 'look-ahead' and plan various sub-goals that involve placing the beads in positions that will not be part of the final solution, Shallice (1988) argued that Supervisory Attentional Control is required for successful completion of the puzzle. While Shallice found participants with predominantly left anterior lesions performed significantly worse than controls (Shallice, 1982; Shallice & Burgess, 1991), other studies have failed to find these differences (Levin, Goldstein, Williams, & Eisenberg, 1991). One of the questions often posed regarding the 'Tower of London' relates to the extent to which it is a specific test of attention, as opposed to a more generalised measure of intelligence (van Zomeren & Brouwer, 1994).

Other tests that are used in the assessment of Supervisory Attentional Control include the Digit Span Backwards sub-test of the Wechsler Intelligence and Memory Scales (Black, 1986; Cohen et al., 1993), and the Six Elements Test (Shallice & Burgess, 1991). Digit Span Backwards involves participants listening to a sequence of digits and repeating back the sequence in the reverse order. The Six Elements Test (Shallice & Burgess, 1991), on the other hand, was developed as a research task to investigate Supervisory Attentional Control in a situation in which participants have to plan their behaviour over relatively long periods of time and to set priorities in order to deal with two or more competing tasks (Kinsella, 1998).

The task requires the participant to carry out two sets of three open-ended tasks, within a 15 minute period. These tasks include dictating a route, carrying out arithmetic problems, and writing down the names of approximately 100 pictures of objects (Shallice & Burgess, 1991). More recently, a modified version of the Six Elements Test was incorporated into the Behavioural Assessment of the Dysexecutive Syndrome (Wilson, Alderman, Burgess, Emslie, & Evans, 1996), which was designed to provide an ecologically valid measure of executive function.

In summary, there are a number of measures that are available to the clinician to assess most of the components of attention (refer to Table 4.1). However, as will be discussed in Sections 4.4 and 4.5, some of these tests may be considered a measure of more than one of these components, reflecting the lack of specificity of these measures.

TABLE 4.1 Clinical Measures of Attention

Components of Attention	Clinical Measures
Arousal	Behavioural observation
Orienting	Not usually assessed clinically
Hemi-Attention	Line Bisection Task Behavioural observation
Focussed Attention	Stroop Ruff 2s and 7s
Divided Attention	PASAT Trail Making Test
Sustained Attention	Ruff 2s and 7s Continuous Performance Test Symbol Digit Modalities Test
Supervisory Attentional Control	Tower of London Six Elements Backward Digit Span

4.3 Questionnaire Measures of Attention in Everyday Life

As the behavioural observations of clinicians are usually confined to the clinic situation, it is also important to obtain a reliable indication of an individual's performance in his/her everyday environment. There are a number of checklists and questionnaires that have sought to quantify the observations of patients and/or their significant others. Examples of such measures include the Trauma Complaints List (van Zomeren & van den Burg, 1995), the Head Injury Family Interview (Kay, Cavallo, Ezrachi, & Vavagiakis, 1995), the Test of Attentional Style (van den Bosch, Rombouts, & van Asma, 1993), and the Rating Scale of Attentional Behaviour (Ponsford & Kinsella, 1991). The Test of Attentional Style is one of the few questionnaire measures that have focussed specifically upon attentional function (van den Bosch et al., 1993). Although the questionnaire was designed originally for a psychiatric population, the test items are equally relevant to a range of clinical populations.

The Rating Scale of Attentional Behaviour (Ponsford & Kinsella, 1991) is another example of a scale that focuses specifically upon attentional function. Of particular importance is that this scale was developed for use with people who have sustained a severe TBI and who are still in rehabilitation settings. The scale consists of 14 items which are scored on a five-point scale, according to their frequency of occurrence. The items in this scale were chosen to reflect a broad range of observable behaviours that are linked to the components of attention described previously (i.e. alertness, selective attention – focussed and divided, and sustained attention) (Ponsford & Kinsella, 1991). Although the scale was originally designed to be used by therapists within a rehabilitation context, it can also be completed by patients and their significant others. The Rating Scale of Attentional Behaviour therefore provides an important adjunct to objective assessments of attention.

4.4 The Test of Everyday Attention (TEA)

The Test of Everyday Attention (TEA) (Robertson et al., 1994) is a clinical test of attention that was specifically developed to provide a measure of attention that incorporated more naturalistic (i.e. ecologically valid) test items. It was developed in line with the Posner and Peterson (1990) model of attention, and includes sub-tests designed to assess the *selection* and *vigilance* systems identified within this model. However, the TEA does not assess the orienting component of Posner's model. The content of the TEA involves more ecologically valid tasks than conventional measures and incorporates relatively familiar materials or concepts, such as maps and telephone directories. The test is centred around an imaginary holiday in Philadelphia, in the USA. During the course of this imaginary holiday, participants are presented with a number of tasks, including having to search for various locations on a road map (*Map Search*) or for particular entries in an extract from the telephone Yellow Pages (*Telephone Search* and *Telephone Search While Counting*). The test includes eight sub-tests and takes approximately 50 minutes to administer. One of the key features of the TEA is that it is one of the few, if not the only, tests of attention that includes a dual task condition. Moreover, Crawford, Sommerville, and Robertson (1997) have extended the clinical utility of the TEA by providing methods for analysing individual sub-test profiles. Kinsella (1998), in a review of the literature on the assessment of attention following TBI, suggests the Test of Everyday Attention (TEA) offers a much needed addition to the range of assessment tasks available to the clinician.

Following the development of the TEA, Robertson et al. (1994, 1996) carried out a principal components analysis of both the TEA and a range of established neuropsychological tests (e.g. Stroop, Trails B, Wisconsin Card Sorting Test, Backward Digit Span, d2 Cancellation Task, PASAT) in order to identify the factors that underlie these measures. This analysis was based on a group of 154 healthy controls and revealed the factors of *visual* *selective attention/speed*, *attentional switching*, *sustained attention*, and *auditory-verbal working memory* (Robertson et al., 1994). Furthermore, Robertson et al. (1994) concluded that the factor structure of the TEA accords well with the Posner and Peterson (1990) model of attention, with the *visual selective/speed*, *attentional switching*, and *auditory-verbal working memory* factors equating to Posner's selection system, and the *sustained attention* factor equating to Posner's vigilance system (Robertson et al., 1994).

4.5 Limitations of Current Measures of Attention

It was noted previously that the majority of the tests of attention used within clinical practice have been 'borrowed' from more global measures of intellectual functioning. As a result, many of the measures that are used are highly multifactorial in nature, assessing a number of cognitive processes in addition to attention. Thus, any deficits in performance on these tasks cannot be attributed to attentional impairment alone. Indeed, it is the multi-factorial nature of current clinical measures that provides one of the greatest obstacles to the assessment of attentional function following TBI (Kinsella, 1998).

A further limitation of many of the measures of attention is that they do not correlate particularly well with subjective reports (by patients or their carers) of functional impairments in everyday life (Ponsford; 1988; Ponsford & Kinsella, 1991). This limitation has sometimes been attributed to the fact that many of these tests lack ecological validity (Kerns & Mateer, 1996). Ecological validity refers to the extent to which an assessment task mimics the situations that individuals are faced with in their everyday life and is particularly important in the rehabilitation context. Sloan and Ponsford (1995) have argued that current measures of attention are not sufficiently sensitive to assess the various aspects of attention involved in everyday life. They suggest that some attentional problems may only become apparent in more complex and less structured 'real world' settings, and over longer periods of time, than are provided in conventional assessment situations. Indeed, Kerns and Mateer (1996) state that "*...psychometric assessment systematically reduces just those variables that challenge attentional resources and capacities in real life situations*" (p.165).

Another concern with established measures of attention is that the majority of these measures are not based on any particular theory of attention (Sohlberg & Mateer,1989). The absence of clear links between an attentional model and assessment measures is hardly surprising given that, until recently, there was little consensus regarding the basic components of attention within the literature. However, recent developments, based mainly upon the work of Posner and colleagues (Posner, Cohen & Rafal, 1982; Posner, Inhoff, Friedrich & Cohen, 1987; Posner, Walker, Friedrich & Rafal, 1984), have culminated in a model of attention that is now being utilised in the development of both clinical and experimental measures of attention (e.g. Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994; 1996).

4.6 The Assessment of Attention Following Severe TBI

Deficits in attention are a commonly reported sequelae to severe TBI (Gronwall, 1987; van Zomeren & Brouwer, 1987; Whyte et al., 1998). The accurate assessment of attention is therefore central to establishing the presence and nature of any attentional deficits, and the monitoring of changes in attentional function in the months following an injury. This section outlines the findings of studies that have assessed the various components of attention in individuals who have sustained a severe TBI. The Test of Everyday Attention (TEA) is also discussed, as is a behavioural rating scale.

4.6.1 Conventional Measures of Attention and TBI

Studies that have utilized conventional neuropsychological measures to assess both focussed and divided attention following severe TBI have provided inconclusive results. The performance of TBI participants on the Stroop sub-tests, for example, has revealed that they produce less correct responses than Controls, indicating a reduced speed of information processing amongst TBI participants (Ponsford & Kinsella, 1992). However, similar interference effects have been found in TBI and Control groups, suggesting that focussed attention is not impaired following severe TBI (Ponsford & Kinsella, 1992; Stuss et al., 1985; van Zomeren, Brouwer, and Deelman, 1984; Spikman, van Zomeren, & Deelman, 1996). In contrast, Bohnen et al. (1992), using a modified sub-test of the Stroop, found that the interference effect associated with this sub-test was able to detect deficits in focussed attention in a group of mild TBI participants.

Another task that is often used to assess both focussed and sustained attention is the Ruff 2s and 7s Selective Attention Test (Ruff, Evans, & Light, 1986). Ruff et al. (1992) demonstrated the ability of the 2s and 7s Selective Attention Test to differentiate between brain injured individuals and Controls. This measure has also been found to predict return to work and study following TBI (Ruff et al., 1993).

A number of studies have used the PASAT to examine attentional function and, in particular, divided attention following severe TBI. For example, Gronwall found that an inter-stimulus interval of two seconds on the PASAT was able to discriminate between healthy control participants and participants who had sustained a mild TBI (Gronwall, 1977; Gronwall & Wrightson, 1974). Stuss, Stethem, Hugenholtz, and Richard (1989) found the performance of moderate to severe TBI participants on each of the four conditions of the PASAT to be impaired. However, Ponsford and Kinsella (1992) found that the decline in performance of their severe TBI participants, across the four conditions of the PASAT, was proportional to that of the control participants. Ponsford and Kinsella (1992) therefore concluded that there was no evidence of a divided attention deficit in their TBI participants. More recently, Park et al. (1999) combined the PASAT with a secondary recognition task and found evidence of a divided attention deficit following severe TBI.

The PASAT has also been used to monitor the recovery of individuals following TBI (Kinsella, 1998). While transitory deficits in divided attention have been reported following mild TBI, persistent deficits have been found following severe TBI (Gronwall, 1987; Ponsford & Kinsella, 1992). Unfortunately, the PASAT places considerable stress upon the patient and, as a result, it has been recommended that its use in clinical practice be confined to investigating situations where subtle attentional deficits are likely (Lezak, 1995).

Discrepant findings have also been reported on tasks used to assess supervisory attentional control following severe TBI. For example, Veltman, Brouwer, van Zomeren, and van Wolffelaar (1996) found that their severe TBI participants were significantly impaired on a tracking task which was designed to assess supervisory attentional control. Deficits in supervisory attentional control following severe TBI have also been detected using the Six Elements Test (Kimonides, 1995; Shallice & Burgess, 1991). However, two studies that have used the Tower of London test to assess supervisory attentional control have failed to find any deficits amongst severe TBI sufferers (Ponsford & Kinsella, 1992; Veltman et al., 1996).

A number of authors have suggested that these mixed findings are the result of the multifactorial and diverse nature of many of the measures used (Kinsella, 1998; Sherman, Strauss, & Spellacy, 1997; Shum, McFarland, & Bain, 1994). It has also been suggested that, where differences between severe TBI and Control groups have been found, these differences may reflect deficits in other cognitive processes (e.g. reduced speed of information processing) rather than genuine deficits in attention (Ponsford & Kinsella, 1992; Spikman, van Zomeren, & Deelman, 1996; van Zomeren & Brouwer, 1987). Other authors, such as

Bohnen et al. (1992), have claimed that the failure to find specific attentional deficits amongst severe TBI participants reflects a lack of sensitivity in the measures that are used. For example, a number of studies have found that the Stroop interference effect has not been able to differentiate between TBI and Control groups (Ponsford & Kinsella, 1992; Stuss et al., 1985). However, Bohnen et al. (1992) found that the interference effect generated by the introduction of a fourth, more sensitive sub-test, was able to differentiate even mild TBI participants from Controls.

4.6.2 The Test of Everyday Attention and TBI

Robertson et al. (1996) compared a group of 15 moderate and severe TBI participants with their normative sample and found that the TBI group performed significantly worse than controls on the Map Search, Telephone Search, Telephone Search While Counting, and Lottery subtests. These findings were taken by Robertson et al. (1996) to provide evidence of selective and sustained attentional problems in individuals with TBI.

Despite the potential benefits of the TEA over other tests of attention, there have been surprisingly few other studies that have examined the performance of TBI groups on the TEA, or compared it to other tests of attention. In fact, the only known published papers come from the work of Chan and colleagues (Chan, Lee, & Hoosain, 1999; Chan, 2000). Using a Cantonese version of the TEA, Chan (2000) found that a group of mild-moderate TBI participants showed long term improvements, relative to controls, on the majority of TEA subtests. It was concluded from this study that the TEA was able to identify problems with *sustained*, *selective*, and *divided attention*, as well as *attentional switching*, following mild-moderate TBI. Of note, however, is the fact that the Chan (2000) study was based on a sample who specifically presented with subjective complaints of attentional problems in their day to day lives. This selection criteria may have biased the sample and increased the likelihood that attentional problems would be detected.

In addition to the above findings, Chan and colleagues (Chan et al., 1999) claimed to replicate the four factor structure reported by Robertson et al. (1994; 1996) in a sample of normal controls. Although the sub-tests that constituted the first factor were essentially the same as those in the Robertson et al. (1996) analysis, there were noticeable differences in the sub-tests that constituted the remaining three factors. This was particularly so for the fourth factor, which Chan et al. (1999) termed *divided attention*. However, the Telephone Search While Counting sub-test was the only test that loaded on this factor, which raises significant concerns regarding its interpretation as a factor.

4.6.3 Self and Significant Other Reports following TBI

The ability to incorporate and quantify the observations of TBI sufferers, their significant others, and their therapists, is an important but often neglected component of the assessment of attention following TBI. The Rating Scale of Attentional Behaviour (Ponsford & Kinsella, 1991) provides an important adjunct to the objective assessment of attention following severe TBI. Of the 14 items within this questionnaire, a ‘slowness in performing mental tasks’ was the most commonly reported difficulty following severe TBI (Ponsford & Kinsella, 1991). This finding is consistent with a number of neuropsychological studies which have found reduced speed of information processing to be the basis of the attentional deficits following TBI. However, despite the existence of the Rating Scale of Attentional Behaviour, it has not been widely used by psychologists in clinical practice or in experimental studies (Cohen et al., 1993).

4.7 Summary

To summarise, the current chapter reviewed measures that assess the key components of attention; namely arousal, orienting, hemi-attention, focussed attention, divided attention, sustained attention, and supervisory attentional control. The relatively recently published TEA, which aims to provide a more ecologically valid measure of attention, was also discussed. A number of limitations of some of these measures were identified, including the lack of a theoretical base, multifactorial nature, and lack of ecological validity. The importance of assessing the qualitative and naturalistic aspects of attentional behaviour was also highlighted within the chapter, with the Rating Scale of Attentional Behaviour being identified as a potentially useful instrument for this purpose.

While attentional deficits are commonly reported by persons who have sustained a severe TBI, studies that have utilized conventional neuropsychological measures have provided inconclusive results. For example, while some studies have found deficits in focussed (e.g Ruff et al., 1992) and divided attention (e.g. Park et al., 1989; Stuss et al., 1989) following severe TBI, others have failed to find any such deficits (e.g. Ponsford & Kinsella, 1992; van Zomeren et al., 1984). In addition, where deficits have been found, some authors have attributed these deficits to a reduced speed of information processing rather than deficits in specific attentional processes (Ponsford & Kinsella, 1992; Spikman et al., 1996). These inconclusive and mixed findings have been attributed to the limitations of many of the currently available measures of attention. The clinician is therefore faced with a significant dilemma in terms of the selection of the most appropriate measures to assess attention. The TEA however, does seem to hold some promise as an assessment measure, not only because it has attempted to address issues of ecological validity but because it is also one of the few clinical tests that has been built upon a specific model of attention. It is therefore surprising that the TEA has not received more prominence in the research literature, particularly in terms of evaluating its efficacy as a complimentary or alternative instrument in the assessment of attention following TBI.

4.8 Study 4[1]

4.8.1 Aims and Hypotheses

This study sought to examine the attentional deficits of a group of participants who had sustained a severe TBI using a range of established tests of attention (i.e. Stroop, SDMT, Digit Span, Ruff 2s and 7s Test of Selective Attention, PASAT), the TEA, and the Rating Scale of Attentional Behaviour. These tests were designed to provide objective and subjective assessments of focussed, divided, and sustained attention.

The specific aims and hypotheses of the present study were:

Aim 1

To examine the ability of these tests of attention to detect deficits in focussed, divided, and sustained attention, and supervisory attentional control, following severe TBI. It was hypothesised that

Hypothesis 4.1(a):

> *While there would be significant differences between the TBI and Control groups on the Stroop Colour-Word and Modified Colour Word sub-tests, there would be no significant differences between the groups on the interference measure (Colour-Word score minus Colour score).*

This hypothesis was based upon the findings of Ponsford and Kinsella (1992) reported previously. However, it was further hypothesised that

Hypothesis 4.1 (b):

> *the interference effect calculated from the Modified Colour-Word sub-test would reveal significant differences between the two groups.*

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[1] The original analysis of this study, using the NART-R as an estimate of premorbid IQ, was published in Bate, Mathias, and Crawford (2001b). Performance on the Test of Everyday Attention following severe traumatic brain injury. *The Clinical Neuropsychologist, 15 (3)*, pp. 405-422.

Hypothesis 4.2:

There would be significant differences between the two groups on both the written and oral versions of the SDMT.

Hypothesis 4.3:

While there would be no significant difference between the two groups on the Forward Digit Span sub-test of the WMS-R, there would be a difference on the Backward Digit Span sub-test.

Hypothesis 4.4:

There would be significant differences between the two groups on the Total Score of the Ruff 2s and 7s Selective Attention test. It was also hypothesised that Control participants would display higher sub-scores on the automatic blocks (i.e. blocks containing alphabetic characters) than on the controlled blocks (i.e. blocks containing numeric characters). However, given that controlled processing is thought to be under the influence of the frontal lobes, it was predicted that the frontal lobe damage associated with TBI would lead to a greater decrement in performance on this task, and therefore a greater decrement between automatic and controlled processing scores, compared to controls.

Hypothesis 4.5:

There would be significant differences between the two groups on the PASAT. In addition, the TBI group would display a greater decrement in performance, than the Control group, as the pacing rate increased.

Hypothesis 4.6:

> *In line with the findings of Robertson et al. (1994; 1996), TBI participants would display deficits on the Map Search, Telephone Search, Telephone Search While Counting, and Lottery sub-tests of the TEA.*

Aim 2

To examine the relationship between the TEA and these other measures of attention and, in particular, the factor structure underlying these measures.

Hypothesis 4.7

> *It was hypothesised that a principal components analysis would reveal a four factor structure consistent with that of Robertson et al. (1994; 1996), namely visual selective attention, attentional switching, sustained attention, and auditory-verbal working memory.*

Aim 3

To determine which clinical measure, or combination of measures, best discriminated between the two groups.

Hypothesis 4.8:

> *It was hypothesised that the interference effect associated with the Modified Colour-Word sub-test of the Stroop, the 1.2 sec. rate of the PASAT, the Elevator Counting with Reversal, and Telephone Search While Counting would best discriminate between the two groups. The Modified Stroop Colour-Word test and the PASAT were chosen because in previous studies they have been found to be able to differentiate between mild TBI and Controls. Similarly, it was predicted that the dual task within the TEA (Telephone Search While Counting) would be a sensitive measure of attentional deficits.*

Aim 4

To examine differences between the TBI and Control groups on both self and significant-other reports of attentional function in everyday life.

Hypothesis 4.9:

> *It was hypothesised that both self and significant-other reports would indicate that TBI participants were experiencing more difficulties with attention in their everyday life than the Controls.*

Aim 5

To examine the relationship between the objective measures (i.e. clinical measures and the TEA) and the subjective measures on the Rating Scale of Attentional Behaviour.

As reported earlier in this chapter, one of the limitations of conventional measures of attention is a lack of ecological validity. The TEA was designed specifically to address this issue. This study therefore examined the relationship between performance on both the TEA and conventional measures of attention and, self/significant other reports of attention in everyday life. Thus, it sought to determine whether the TEA was a more ecologically valid measure than existing conventional measures. In addition, as the focus of the current study was upon the ecological validity of the TEA in assessing severe TBI, it was decided to calculate the correlations for the TBI and Control groups separately.

Hypothesis 4.10:

> *It was hypothesised that higher correlations would exist between the TEA sub-tests and the Rating Scale of Attentional Behaviour, than between the conventional neuropsychological measures and the Rating Scale of Attentional Behaviour, for the TBI group.*

4.8.2 Method

4.8.2.1 Participants

The 35 TBI and 35 Control participants in this study were the same as those described in Study 1 and Study 2. The demographic and clinical screening data for the TBI and Control groups were provided in Table 3.1 (page 75).

4.8.2.2 Tasks

Stroop Colour Word Test (Bohnen et al., 1992; Golden, 1978)

The Stroop is considered to be a measure of selective attention (Lowe & Mitterer, 1982) and is made up of four sub-tests. Participants are given 45 seconds to complete each of the four sub-tests, with each sub-test containing 100 words. In the first sub-test participants are required to read aloud, as quickly as possible, colour names (e.g. red, blue, yellow, red etc.) printed in black type. The second sub-test involves participants having to name the colour of each block of four Xs (e.g. xxxx or xxxx). These blocks of four Xs are printed in the same array as the words in the first sub-test. In the third sub-test participants are again required to read aloud the colour names. However, each word is printed in a coloured ink that does not match the word meaning (e.g. the word 'red' may be printed in blue ink). The participant is asked to name the colours that the words are printed in, as quickly as possible, while ignoring the word meaning. The magnitude of the difference between the number correct on the second (Colour) and third (Colour-Word) sub-tests provides an index of the interference effect (selective attention). The final sub-test was developed by Bohnen et al. (1992). In this sub-test the response sheet is essentially the same as in sub-test 3, except that there are small rectangles (0.8 x 2.0mm) drawn around twenty of the words. Participants are instructed to name the colours of the printed words in the same way as in the third (Colour-Word) sub-test. However, when they come to one of the boxed items, they are required to read the word rather than name the colour in which it is printed (Bohnen et al., 1992). The magnitude of the difference between this sub-test and the second (colour-naming) sub-test is calculated to determine the interference effect (hereafter referred to as the modified interference effect). This modified interference effect is regarded as an indicator of deficits in selective attention.

Symbol Digit Modalities Test (SDMT) (Smith, 1973)

The SDMT principally assesses complex visual scanning and visual tracking, as well as providing an indicator of sustained visual attention (Lezak, 1995; Shum et al., 1990). With the assistance of a key to show which symbol corresponds with which number, participants were given 90 seconds to fill in the blank spaces below a series of symbols with the corresponding number. Both oral and written versions of the test were presented (counterbalanced for order across participants). The score is the total number of squares completed correctly on each trial (max. score = 110).

Digit Span *(Wechsler, 1987)*

Both the forward and backward span sub-tests of the revised Wechsler Memory Scale (WMS-R) were administered. The forward span sub-test requires participants to repeat a sequence of digits exactly as they are presented by the examiner. Two separate sequences of the same length are presented, with the sequence length being increased by one digit after each sequence pair. The test is terminated when the participant either fails a pair of sequences of the same length or is able to repeat a nine digit sequence correctly. The procedure for the backward span sub-test is almost the same except that the participant's task is to repeat the digits in exactly the reverse order. While the forward span is considered to provide a measure of the efficiency of attention (freedom from distractibility), backward span draws more upon working memory (Lezak, 1995). In addition, it has been suggested that the reversal operation in the backward span test also draws upon Supervisory Attentional Control (Black, 1986;

Cohen & O'Donnell, 1993). The score on each of these sub-tests represents the maximum number of digits that can be recalled by an individual (maximum scores: Forwards = 8; Backwards = 7).

Ruff 2s and 7s Selective Attention Test (Ruff, Evans, & Light, 1986)

Participants were given 15 seconds to cross out as many 2s and 7s as they could which are mixed into three lines of either alphabetic or numeric characters. They were instructed to start from the left side of the top line and proceed to the second and third lines in a similar fashion. Each line consisted of 50 characters and there were 10 target numbers (i.e. 2 or 7) embedded within each line. After 15 seconds, participants were given the command "next" signifying that they were to move immediately onto the next block of three lines. There were 20 blocks in total, 10 made up of capitalised alphabetical characters and 10 made up of numerals. Four scores were derived; (1) the total number of digits correctly cancelled out over the 20 blocks (Total); (2) the number of digits correctly cancelled in the 10 blocks of alphabetic characters (Automatic); (3) the number of digits correctly cancelled in the 10 blocks of numeric characters (Controlled), and (4) the difference between the Automatic and Controlled scores (i.e. Automatic minus Controlled).

Paced Auditory Serial Addition Test (PASAT) (Gronwall & Sampson, 1974)

While the PASAT was originally designed to provide a measure of information processing capacity, it is also widely considered to be a test of divided attention (Kinsella, 1998). Participants were presented with a random series of auditory tape-recorded digits (1-9) and instructed to add pairs of numbers such that each number is added to the one immediately preceding it. The task is presented at four different speeds, with a 2.4, 2.0, 1.6, or 1.2 second inter-stimulus interval. The total number of correct responses were computed for each pacing (maximum possible = 60).

Test of Everyday Attention (TEA) *(Robertson et al. 1994)*

Participants are asked to imagine that they are on holiday in Philadelphia, in the USA, and are informed that they will be presented with various scenarios (8 sub-tests) during the course of this imaginary holiday.

Map Search: This is a test of visual selective attention in which participants are required to search for designated symbols representing certain locations or services (e.g. the symbol of a knife and fork representing a restaurant) on a coloured map of Philadelphia. Two minutes are allowed to complete the task. Performance is scored in terms of the number of symbols found within a 2 minute period, with the maximum possible score being 80.

Elevator Counting: In this test of sustained attention, participants are asked to imagine that they are in an elevator whose floor-indicator is not functioning. They therefore have to establish which 'floor' they have arrived at by counting a series of tape-recorded tones which indicate where they are, having started from the ground floor. Seven strings of tones are presented, with the subject's score indicating the number of strings that are correctly counted (maximum score = 7).

Elevator Counting with Distraction: This task, in addition to involving auditory selective attention, also draws upon auditory-verbal working memory. Participants have to count the same pitched tones that were used in the last sub-test but this time they have to ignore the interspersed high pitch tones which have been introduced as distractors. Once again, the score indicates the number of strings counted correctly, giving scores ranging from 0 to 10.

Visual Elevator: The Visual Elevator sub-test is considered to be a measure of attentional switching. Participants are asked to count a series of drawings of elevator doors that are presented in rows on the pages of a presentation booklet. The task is self-paced. The drawings of the elevator doors are interspersed with large up- or down-pointing arrows, indicating that the direction of counting should change in line with the arrow (i.e. up or down). Two separate scores are derived from this subtest: the first score represents the number of visual strings counted correctly (maximum score = 10) and the second score is a timing score calculated by dividing the total time taken for the correct items by the total number of switches for the correct items. Lower values represent superior performance on this timing score.

Auditory Elevator with Reversal: This task measures attentional switching and is presented at a fixed speed on audio-tape. Participants are required to count strings of 'medium' pitched tones. Interspersed with these 'medium' pitched tones are both high (indicating that the participant must switch to counting up) and low tones (indicating that the participant must switch to counting down). The score represents the number of strings of tones that are counted correctly (maximum = 10).

Telephone Search: This is a visual selective attention task in which participants must look for designated symbols and ignore other symbols, while searching entries in a simulated classified telephone directory. Beside each entry in the telephone directory are two symbols (star, square, circle, or cross). When two of the same symbols occur together (e.g. two stars), the subject must circle them with a water-based coloured pen. The score is calculated by dividing the total time taken by the number of symbols detected. The maximum number of symbols that can be detected is 20. Lower values represent superior performance on this sub-test.

Telephone Search (Dual Task): While this task loaded on the sustained attention factor in the factor analysis of Robertson et al. (1994), it has also been described as a measure of divided attention (Chan, 2000). In this task, the subject must again search the telephone directory while simultaneously counting strings of tones presented by a tape-recorder. This sub-test yields a 'dual task decrement' score, which is calculated by subtracting the time-per-target score of the previous sub-test from the time-per-target score on the current sub-test, with the latter score being weighted for accuracy of tone counting. Lower and negative values represent superior performance on this sub-test.

Lottery: In this sub-test, which is considered to be a measure of sustained attention, the subject listens to a series of alpha-numeric strings presented by a tape-recorder. The scenario to be imagined for this task is that the subject has bought some lottery tickets and is listening to the announcement of winning numbers on the radio. All alpha-numeric strings are in the form of two letters followed by three numbers. Participants are instructed to write down the two letters preceding all numbers that end in 55. These are considered 'winning' numbers. There are 10 'winning' numbers randomly included during the 10 minute presentation. The participants score is the number of correctly recorded numbers (maximum = 10).

Rating Scale of Attentional Behaviour (Ponsford & Kinsella, 1992)

This 14 item questionnaire was presented both to participants and a 'significant other' person (e.g. family member, friend, carer). Participants were asked to respond to a series of statements relating to their current attentional abilities using a five point scale (1=*not at all, 2=occasionally, 3=sometimes, 4=almost always, 5=always).* The higher the score, the greater the degree of attentional difficulty.

National Adult Reading Test - Revised (UK)

As with the previous studies within this thesis The National Adult Reading Test - Revised (NART-R UK) was originally included as an estimate of premorbid IQ (refer to page 79 for further details).

4.8.2.3 Procedure

The data were gathered as part of a larger study investigating deficits in attention following TBI (refer to Studies 1 and 2). The Ishihara (1972) screening test was used to identify any participants with colour vision deficiencies. One participant was identified with a colour vision deficiency. As a result, the Stroop was not administered to this participant, as it relies heavily upon intact colour vision. In addition, the Line Bisection Test (Diller et al., 1974) was administered to screen for the existence of any hemi-neglect. Test presentation was counterbalanced to control for any effects of order. Testing was completed in a single session lasting approximately 110 minutes.

4.8.3 Results

4.8.3.1 Matching Variables

As discussed in Chapter 3, one-way ANOVAs revealed that while the TBI and Control Groups had been successfully matched for age and education, there was a significant difference between the two groups in terms of estimated premorbid IQ ($F(1, 68) = 7.15$, $p = .009$, partial $\eta^2 = .095$) (refer to Table 3.1, p. 75). As a result of this difference between the two groups the original analysis of the Study 4 data included the NART-R as a covariate to control for the effects of premorbid IQ (Bate et al., 2001b). However, because of recent concerns about the validity of the NART as a measure of premorbid IQ following severe TBI (e.g. Freeman et al., 2001; Riley & Simmonds, 2003), it was decided to not include the NART-R as a covariate in the current analyses. If the NART is affected by severe TBI, then the use of this measure as a covariate may serve to 'remove' the effect of the injury itself.

Within Studies 1 to 3, the Finger Tapping Test (Bornstein, 1986; Spreen & Strauss, 1991) was included to control for the effects of any deficits in motor speed upon RTs on the COAT. The

Finger Tapping Test closely resembled the finger tapping response within the COAT. In fact, identical button pads were used in both tasks. Although response time was a significant factor on a number of the neuropsychological and TEA sub-tests within Study 4, the timed response was, in the majority of instances, a verbal response. As a result it was decided not to include the finger tapping test as a covariate in Study 4.

4.8.3.2 Statistical Analyses

Univariate F ratios were calculated for the conventional neuropsychological measures of attention and the sub-tests of the TEA in order to determine whether there were differences between the TBI and Control groups on these tests (Aim 1). The problem of making multiple comparisons was noted and a Bonferroni correction was considered. However, because the tests were designed to provide different measures of the construct of attention, and given the expected relationship between the variables, such a correction would be too conservative. A repeated measures ANOVA was additionally used to examine the scores from each condition of the PASAT. Pearson correlation coefficients were then calculated and a principal components analysis carried out to determine the relationship between the TEA and the established neuropsychological measures (Aim 2). A logistic regression was also completed in order to determine which combination of attentional measures best discriminated between the TBI and Control groups (Aim 3). A Group by Informant repeated measures ANOVA was carried out to determine whether there were any group differences on either the self or significant-other reports of attentional problems in the two groups. In addition, Pearson r correlation coefficients were calculated to determine the relationship between the Rating Scale scores and each of the neuropsychological measures (Aim 4). All data were analysed using SPSS version 11.5 (SPSS, 2002).

4.8.3.3 Group differences on attentional measures

Means and standard deviations for the TBI and control groups for each of the tests of attention are provided in Tables 4.2 and 4.3. While all of the sub-tests of the Stroop were administered (refer to Table 4.2), only the scores from the Colour-Word and Modified Colour-Word sub-tests, along with the interference scores (i.e. Colour-Word minus Colour, and Modified Colour-Word minus Colour) were analysed, as the word reading (Word) and colour naming (Colour) sub-tests are not considered to be specific measures of attention. Consistent with Hypothesis 4.1(a) ANOVAs revealed significant differences between the two groups on the Colour-Word ($F(1,67) = 23.54$, $p = .000$, partial $\eta^2 = .260$) and Modified Colour-Word ($F(1,67) = 41.87$, $p = .000$, partial $\eta^2 = .385$) sub-tests. Also consistent with Hypothesis 4.1(a), there were no significant differences between the two groups on the Stroop interference effect ($F(1,67) = 3.79$, $p = .056$, partial $\eta^2 = .051$). However, contrary to Hypothesis 4.1(b), there was no difference between the two groups on the Modified Stroop interference effect ($F(1,67) = 2.87$, $p = .095$, partial $\eta^2 = .041$).

TABLE 4.2 Means, standard deviations, and significance levels for each of the conventional measures of attention.

	TBI (n=35)		Control (n=35)		
	M	**SD**	**M**	**SD**	**sig.**
Stroop					
Word (W) [a]	80.4	(17.0)	104.4	(19.4)	
Colour (C) [a]	60.7	(10.9)	75.7	(13.1)	
Colour Word (CW)	36.8	(8.5)	47.5	(9.6)	***
Modified Colour Word (MCW)	33.0	(6.7)	44.3	(7.8)	***
Interference Effect (CW minus C)	-23.9	(9.2)	-28.3	(8.5)	
Modified Interference Effect (MCW minus C)	-27.8	(9.7)	-31.5	(9.4)	
SDMT					
Written Correct	42.4	(10.4)	58.6	(12.6)	***
Oral Correct	49.8	(12.3)	67.8	(13.7)	***
WMS-R Digit Span					
Forward Span	6.4	(1.1)	6.8	(1.1)	
Backward Span	4.9	(1.1)	5.4	(1.2)	
Ruff Selective Attention Test					
Total	209.3	(45.3)	262.5	(44.7)	***
Automatic Correct	104.7	(24.7)	134.3	(24.7)	***
Controlled Correct	104.6	(21.4)	128.2	(21.6)	***
Automatic – Control	0.03	(9.3)	6.0	(12.6)	
PASAT					
Total Correct					
2.4	36.0	(11.2)	43.1	(12.0)	*
2.0	33.6	(11.0)	40.8	(10.6)	**
1.6	27.9	(9.0)	36.7	(10.1)	***
1.2	22.0	(8.4)	29.5	(6.0)	***

[a] group comparisons on these sub-tests were not made as they are not considered specific tests of attention.

SDMT = Symbol Digit Modalities Test; WMS-R = Wechsler Memory Scale – Revised;
PASAT = Paced Auditory Serial Addition Test.

* p<.05 **p<.01 *** p<.001

TABLE 4.3 Means, standard deviations, and significance levels for each of the TEA sub-tests.

	TBI (n=35)		Control (n=35)		
	M	**SD**	**M**	**SD**	**sig.**
TEA Map Search	64.0	(14.3)	77.1	(3.7)	***
Elevator Counting	6.8	(0.5)	6.7	(0.7)	
Elevator Counting with with Distraction	8.9	(1.4)	9.3	(1.3)	
Visual Elevator (Accuracy)	8.5	(1.2)	9.0	(1.0)	
Visual Elevator (Time)	4.2	(1.3)	3.3	(1.1)	**
Elevator Counting with Reversal	6.9	(2.9)	8.2	(1.9)	*
Telephone Search	3.5	(1.0)	2.6	(0.4)	***
Telephone Search while Counting (dual task decrement)`	2.3	(3.3)	1.2	(2.1)	
Lottery	8.3	(1.8)	9.3	(1.4)	*

* $p < .05$ ** $p < .01$ *** $p < .001$
TEA = Test of Everyday Attention.

Highly significant differences and large effect sizes were found when comparing the two groups on both the Oral (F(1,68) = 33.69, p = .000, = partial $\eta^2 = .331$) and Written (F(1,68) = 34.36, p = .000, partial $\eta^2 = .336$) versions of the SDMT (refer to Table 4.3), thus confirming Hypothesis 4.2. In contrast, there were no differences and only relatively small effect sizes between the two groups on the Forward (F(1,68) = 2.65, p = .108, partial $\eta^2 = .038$) and Backward Digit Span (F(1,68) = 3.30, p = .074, partial $\eta^2 = .046$) sub-tests of the WMS-R. While the two groups were predicted to perform at equivalent levels on the Forward Span sub-test, it was predicted that there would be a significant difference between the groups on the Backward Span sub-test. Thus, Hypothesis 4.3 was only partially supported (i.e. there were no differences between the groups on either sub-test).

Large and significant differences between the TBI and Control groups were found on the Ruff 2s and 7s Selective Attention Test Total Score (F(1,68) = 24.45, p = .000, partial η^2 = .264), Automatic Correct (F(1,67) = 25.06, p = .000, partial η^2 = .269), and Controlled Correct (F(1,68) = 21.07, p = .000, = partial η^2 = .237) scores. While significant differences between the two groups on the Total score and the Controlled scores were predicted (Hypothesis 4.4), the difference between the Automatic scores were not. A reduced score on the automatic processing task in the TBI group resulted in the controlled and automatic processing scores of this group being virtually identical. As can be seen in Table 4.3, this contrasts with the pattern displayed by Control participants under the automatic and controlled conditions.

With respect to the PASAT, there were significant differences and predominately large effect sizes between the two groups on the 2.4 second (F(1,66) = 6.26, p = .015, partial η^2 = .087), 2.0 second (F(1,66) = 7.58, p = .008, partial η^2 = .103), 1.6 second (F(1,63) = 13.93, p = .000, partial η^2 = .181) and 1.2 second (F(1,63) = 17.40, p = .000, partial η^2 .216) presentation rates. A Group (TBI, Controls) by Presentation Rate (2.4, 2.0, 1.6, 1.2 sec.) repeated measures ANOVA was subsequently run to further examine the effects of the increased speed across the four PASAT presentation rates. There was a significant main effect and large effect size for Group (F(1,63) = 11.83, p=.001, partial η^2 = .158), indicating that the TBI group performed more poorly overall on the PASAT. There was also a significant main effect and very large effect size for Presentation Rate (F(3,189) = 149.67, p = .000, partial η^2 = .704) indicating that both groups produced fewer correct responses as the presentation speed increased (refer to Table 4.2). However, the absence of a significant Group by Presentation Rate interaction and small effect size (F(3,189) = 1.03, p = .381, partial η^2 = .016) indicated that there was no differential impact on the two groups in response to an increase in presentation rate. As a result, Hypothesis 4.5, which predicted that there would be both an overall difference between the two groups on the PASAT, and that the TBI group would display a greater decrement in performance (than the Control group) as the presentation rate increased, was only partially supported.

When the sub-tests of the TEA were analysed using an ANOVA, the Map Search (F(1,68) = 27.54, p = .000, partial $\eta^2 = .288$), Visual Elevator (timing score) (F(1,68) = 10.56, p = .002, partial $\eta^2 = .134$), Elevator Counting with Reversal (F(1,58) = 4.63, p = .036, partial $\eta^2 = .074$), Telephone Search (F(1,68) = 23.39, p = .000, partial $\eta^2 = .256$) and Lottery (F(1,68) = 6.05, p = .016, partial $\eta^2 = .082$) sub-tests produced significant differences and medium to large effect sizes between the two groups. Thus, Hypothesis 4.6, which predicted that TBI participants would display deficits on the Map Search, Telephone Search, Telephone Search while Counting, and Lottery sub-tests, was supported, except for the absence of a significant difference between the groups on the Telephone Search While Counting sub-test (F1,68) = 2.86, p = .096, partial $\eta^2 = .040$).

In summary, when comparing TBI and Control groups on the established neuropsychological measures, significant group differences were found on the Colour-Word and Modified Colour-Word sub-tests of the Stroop, both the written and oral versions of the SDMT, and each of the four different pacing rates of the PASAT. Contrary to Hypothesis 4.1(b), there was no significant difference between the groups on the Stroop Modified Interference Effect. With regard to the TEA sub-tests, the Map Search, Visual Elevator (timing score), Elevator Counting with Reversal, Telephone Search, and Lottery sub-tests produced significant differences between the groups. However, the relatively small effect sizes for the Elevator Counting with Reversal and Lottery sub-tests show that, while there were statistically significant differences, these differences were only small and unlikely to be clinically significant.

4.8.3.4 Relationship between the TEA and established measures of attention

The correlations between the TEA sub-tests and the established neuropsychological measures for the combined TBI and Control groups are provided in Table 4.3. The TBI and Control groups were combined as correlations between the sub-tests for the Control group alone were largely consistent with those of the combined groups. Notably, the Elevator Counting sub-test, considered to be a test of *sustained attention,* was the only TEA sub-test not to correlate with at least one of the established measures of attention. This was in contrast to the remaining seven TEA sub-tests which correlated with the majority of the established neuropsychological measures. Thus, there was a significant relationship between the TEA and the majority of the established neuropsychological measures of attention, suggesting that both the TEA and the more established measures, at least to some extent, are measuring similar attentional processes.

TABLE 4.4 Correlations between TEA sub-tests and established neuropsychological measures of attention.

	Map Search	Elevator Counting	Elevator Counting with Distraction	Visual Elevator (correct)	Visual Elevator (timing score)	Elevator Counting with Reversal	Telephone Search	Telephone Search while Counting (Dual)	Lottery
Stroop Colour-Word	.53 **	.13	.23	.26 *	-.62 **	.35 **	-.54 **	-.24 *	.40 **
Stroop Modified Colour-Word	.50 **	.17	.24 *	.34 **	-.72 **	.44 **	-.55 **	-.24 *	.39 *
Stroop Interference Effect	-.04	-.03	.04	-.17	.24 *	-.07	.19	.12	-.35 **
Stroop Modified Interference Effect	-.14	-.02	.02	-.14	.24 *	-.04	.26 *	.15	-.41 **
SDMT (written)	.64 **	.12	.21	.36 **	-.61 **	.36 **	-.72 **	-.36 **	.33 **
SDMT (oral)	.61 **	.12	.21	.38 *	-.60 **	.34 **	-.70 **	-.38 **	.37 **

** $p < 0.01$ level (2 tailed)
* $p < 0.05$ level (2 tailed)
SDMT = Symbol Digit Modalities Test; PASAT = Paced Auditory Serial Addition Test

TABLE 4.4 Correlations between TEA sub-tests and established neuropsychological measures of attention. (cont/d)

	Map Search	Elevator Counting	Elevator Counting with Distraction	Visual Elevator (correct)	Visual Elevator (timing score)	Elevator Counting with Reversal	Telephone Search	Telephone Search while Counting (Dual)	Lottery
WMS-R Forwards Digit Span	.08	.17	.05	.14	-.32 **	.14	-.09	-.26 *	.37 **
WMS-R Backwards Digit Span	.12	.08	.10	.30 *	-.38 **	.19	-.15	-.32 **	.37 **
Ruff Selective Attention Test	.62 **	.06	.07	.39 **	-.57 **	.31 *	-.69 **	-.30 **	.40 **
PASAT (2.4 sec)	.33 **	.12	-.01	.35 **	-.59 **	.40 **	-.44 **	-.19	.33 **
PASAT (2.0 sec.)	.32 **	.05	-.02	.37 **	-.60 **	.37 **	-.45 **	-.24 *	.36 **
PASAT (1.6 sec.)	.31 **	.15	.04	.29 *	-.55 **	.32 *	-.46 **	-.22	.34 **
PASAT (1.2 sec.)	.32 **	.19	.08	.21	-.57 **	.31 *	-.45 **	-.23	.38 **

** $p < 0.01$ level (2 tailed)
* $p < 0.05$ level (2 tailed)
SDMT = Symbol Digit Modalities Test; PASAT = Paced Auditory Serial Addition Test

A principal components analysis was carried out in order to determine the replicability of the findings of Robertson et al. (1994, 1996) and Chan et al. (1999). Both TBI and Control groups were included in the analysis as it was felt that, for the component structure to have clinical relevance, it had to represent the continuum of performance across both the Control and TBI populations. In addition, and as mentioned previously, correlations between the sub-tests for the Control group alone were largely consistent with when the two groups were combined. Only one score was used from each sub-test in the analysis, as highly correlated tests can lead to the production of tenuous factors (Robertson et al., 1996). Sub-test scores were chosen on the basis of whether they had been included in the factor analyses of previous authors (e.g. Robertson et al., 1994, 1996; Chan et al. 1999). The sub-tests included in the principal components analysis are outlined in Table 4.5. Using both groups, a subject to variable ratio greater than 5:1 was achieved. A non-orthogonal rotation (oblimin) was used in the current analysis as the factors were not considered to be independent of each other. However, following the oblimin rotation, and in order to more closely replicate the principal component analyses carried out by Robertson et al. (1994, 1996) and Chan et al. (1999), a varimax (orthogonal) rotation was also carried out. There were no differences in the factor structure between the two rotations and only the loadings varied slightly. The results of the oblimin rotation are therefore reported.

The principal components analysis (with oblimin rotation) accounted for 66.9% of the total variance and revealed a four factor structure comprising *visual selective attention*, *attentional switching*, *sustained attention*, and *divided attention* (refer to Table 4.5). A factor loading of greater than 0.4 was required for a test to be included within a particular factor. The factor loading of each test was largely consistent with the components of attention thought to be assessed by the individual tests. For example, the tests which loaded upon Factor 1 (i.e. Map

Search, Telephone Search, Stroop Colour-Word, SDMT-Oral, Ruff 2s and 7s Selective Attention Test) are all considered to be tests of visual selective attention. However, there were some exceptions, with Elevator Counting, which is usually considered a test of sustained attention, loading upon the divided attention factor. As was predicted in Hypothesis 4.7, the factor structure generated within the current study broadly corresponds to the principal components analyses reported by Robertson et al. (1994, 1996). However, given the relatively low number of participants (N=70), and the fact that TBI and Control participants were combined, these results should be interpreted cautiously.

TABLE 4.5 Principal Components Analysis (oblimin rotation) of TEA subtests and established neuropsychological tests of attention.

	Factor 1 Visual Selective Attention	**Factor 2** Attentional Switching	**Factor 3** Sustained Attention	**Factor 4** Divided Attention
Map Search	.946	-.054	-.218	-.023
Telephone Search	-.895	-.033	-.029	.234
Stroop (Colour-Word)	.584	-.257	.217	.228
SDMT (Oral)	.761	-.146	.157	.120
Ruff 2s and 7s Selective Attention Test	.816	.071	.116	.040
Lottery	.082	-.054	.690	-.258
Visual Elevator (correct)	.210	.252	.581	.152
Backwards Digit Span	-.166	-.109	.809	.090
PASAT (2 sec.)	.342	.081	.569	.091
Elevator Counting with Distraction	.060	-.900	-.181	-.016
Elevator Counting with Reversal	.091	-.537	.357	.046
Elevator Counting	.054	-.075	.018	.862
Telephone Search while Counting (dual task decrement)	-.294	-.226	-.232	.495
Eigenvalue	4.97	1.35	1.34	1.05

SDMT = Symbol Digit Modalities Test; PASAT = Paced Auditory Serial Addition Test.

4.8.3.5 Differentiating between the groups

While the preceding analyses revealed that a number of variables individually differentiated between the two groups, these tests have considerable shared variance, as highlighted by the many significant correlations between measures (refer to Table 4.4). In order to determine which measure, or combination of measures, best discriminated between the two groups, a logistic regression using the *Direct Entry* of variables method, was carried out using the 14 measures that differed significantly between the two groups (refer to Tables 4.2 & 4.3). Variable selection was set with an F for entry at .05, and for removal at .10. The logistic regression, which predicted group membership (TBI vs Controls) with 91.4 % accuracy, found that the Map Search sub-test of the TEA (B = .64, Wald = 4.9, p = .026) best differentiated between the two groups. The Modified Colour-Word sub-test of the Stroop just failed to each significance (B = .51, Wald = 3.7, p = .053). Thus, of all the measures examined in this study, the TEA Map Search, which assesses *visual selective attention*, provided the most discriminating and economical assessment of attention in persons who had sustained a severe TBI. As a result, Hypothesis 4.8, which predicted the most discriminating sub-tests to be the interference effect associated with the Modified Colour-Word sub-test of the Stroop, the 1.2 sec. rate of the PASAT, Elevator Counting with Reversal, and Telephone Search While Counting, could not be supported.

4.8.3.6 The Relationship between Objective and Subjective Measures of Attention

Descriptive data for the Rating Scale of Attentional Behaviour are provided in Table 4.6. Of the 35 TBI participants, 34 returned their forms, while all of the Control group participants completed their forms. With regard to the significant other reports, 29 out of the 35 significant others of the TBI group returned their forms. Significant others from the Control group returned 33 out of 35 forms. A Group (TBI, Controls) by Informant (Self-report, Significant Other Report) repeated measures ANOVA was performed in order to examine group differences in subjective reports of attentional problems. This analysis revealed a significant main effect for Group (F(1,57) = 8.23, p = .006, partial $\eta^2 = .126$) and a significant Group by Informant interaction (F(1,57) = 14.01, p = .000, partial $\eta^2 = .197$). The significant main effect for group and large effect size revealed that there were differences between the two groups on the subjective measures. The large interaction effect can be seen in Table 4.6. While there was no difference between self-reports of attentional problems for the TBI and Control groups, significant others reported more problems for the TBI than the Control group. Moreover, compared to their respective significant others, TBI participants appeared to have underestimated their attentional difficulties, while Control participants overestimated theirs. Thus, Hypothesis 4.9, which predicted that both TBI participants and their significant others would report more difficulties with attention in everyday life than would the Controls (and their significant others), was only partially supported.

TABLE 4.6: Means and SDs for the Rating Scale of Attentional Behaviour

	TBI	**Controls**
Self-report	15.6 (9.0)	15.1 (8.0)
Significant Other Report	21.0 (10.3)	10.7 (7.9)

The relationship between self/significant other reports of everyday attentional function and the objective assessments of attention were also examined (Aim 5). Pearson correlation coefficients were calculated separately (for the TBI and Control groups) between the Total scores on the Rating Scale of Attentional Behaviour for the TBI participants and their significant others and each of the neuropsychological measures (refer to Table 4.7). In terms of the self-reports of the TBI group, significant correlations were found with scores on the 1.6 and 1.2 second rates of the PASAT. There were no significant correlations between the self-reports of the TBI group and any of the TEA sub-tests. With regard to the standard neuropsychological measures and the significant other reports of the TBI group, the only significant correlation was with the modified sub-test of the Stroop (Bohnen et al., 1992), and this was in fact a negative correlation. In relation to the TEA, significant correlations were observed between significant other reports of the TBI group and raw scores on the Elevator Counting, and Visual Elevator (timing score). Of note was that the negative correlation between significant other report and Elevator Counting. Thus, Hypothesis 4.10, which predicted that higher correlations would exist between the TEA sub-tests and the Rating Scale of Attentional Behaviour, than between the conventional neuropsychological measures and the Rating Scale of Attentional Behaviour, within the TBI group, was not confirmed. In fact very few correlations were significant and, given the number of correlations, it is suggested that even these correlations be viewed with some caution due to the likelihood of Type 1 errors. As can be seen from Table 4.7 there were only two significant correlations within the Control group.

TABLE 4.7: Pearson Correlation Coefficients, and significance levels, between Total Scores on the Rating Scale of Attentional Behaviour (for Self and Significant Other Reports) and the measures of attention, for (a) TBI and (b) Control groups.

	Self Report	Significant Other Report
(a) TBI Group		
Stroop		
Word (W)	-.01	-.12
Colour (C)	.13	-.07
Colour-Word (CW)	-.07	-.38
Modified Colour Word (MCW)	-.04	-.50 **
Interference Effect (CW minus C)	-.23	-.34
Modified Interference Effect (MCW minus C)	-.18	-.34
SDMT		
Written	.10	-.29
Oral	.08	-.30
Ruff		
Automatic Correct	.10	-.09
Controlled Correct	.06	-.12
PASAT		
2.4 sec. Rate	.16	-.09
2.0 sec. Rate	.30	.07
1.6 sec. Rate	.36 *	.01
1.2 sec. Rate	.38 *	.12
(b) Control Group		
Stroop		
Word (W)	-.13	-.19
Colour (C)	-.27	-.12
Colour-Word (CW)	-.08	.09
Modified Colour Word (MCW)	-.13	-.04
Interference Effect (CW minus C)	.30	.28
Modified Interference Effect (MCW minus C)	.30	.14
SDMT		
Written	-.36 *	-.21
Oral	-.29	-.16
Ruff		
Automatic Correct	-.16	-.22
Controlled Correct	-.14	-.25
PASAT		
2.4 sec. Rate	.12	.33
2.0 sec. Rate	.07	.32
1.6 sec. Rate	-.02	.01
1.2 sec. Rate	-.12	-.02

** $p < 0.01$ level (2 tailed); * $p < 0.05$ level (2 tailed)
SDMT = Symbol Digit Modalities Test; PASAT = Paced Auditory Serial Addition Test

TABLE 4.7: (cont/d) Pearson Correlation Coefficients between Total Scores on the Rating Scale of Attentional Behaviour (for both Self and Significant Other Reports) and the measures of attention, for (a) TBI and (b) Control groups.

	Self Report	Significant Other Report
(a) TBI Group		
TEA		
Map Search	.05	-.35
Elevator Counting	-.33	-.47 *
Elevator Counting With Distraction	-.14	-.15
Visual Elevator (correct)	-.01	-.21
Visual Elevator (timing score)	.13	.47 *
Elevator Counting With Reversal	-.13	-.19
Telephone Search	-.07	.13
Telephone Search While Counting	-.32	-.05
Lottery	-.10	.21
(b) Control Group		
TEA		
Map Search	-.23	.05
Elevator Counting	-.24	-.28
Elevator Counting With Distraction	-.26	-.22
Visual Elevator (correct)	-.01	.06
Visual Elevator (timing score)	.18	.06
Elevator Counting With Reversal	.37 *	.35
Telephone Search	.30	.16
Telephone Search While Counting	-.08	-.17
Lottery	-.02	.07

** $p < 0.01$ level (2 tailed); * $p < 0.05$ level (2 tailed)
SDMT = Symbol Digit Modalities Test; PASAT = Paced Auditory Serial Addition Test

4.8.4 Discussion

The current study was designed to examine the attentional deficits of persons who had sustained a severe TBI using commonly used tests of attention, the TEA, and a questionnaire measure.

4.8.4.1 Established measures of attention

An analysis of the individual measures found that, although the performance of TBI participants on the Colour-Word and Modified Colour-Word sub-tests of the Stroop was significantly poorer than Controls, there were no significant differences between the two groups on either of the interference measures. Whereas deficits on the Word, Colour, and Colour-Word sub-tests principally measure speed of information processing, the interference measures are thought to assess deficits in selective attention (Ponsford & Kinsella, 1992; Spikman et al., 1996). Thus, in line with previous studies (e.g. Ponsford & Kinsella, 1992; Spikman et al., 1996), there was evidence of a reduced *speed of information processing* in the TBI group but there was no evidence of a deficit in *selective* attention.

Consistent with the findings of Ponsford and Kinsella (1992), the SDMT discriminated between TBI and healthy Control participants. A range of studies have found the SDMT to be a highly sensitive, although non-specific, indicator of brain dysfunction (Pfeffer et al., 1981; Smith, 1983). Unfortunately, due to its multi-factorial nature, the finding of reduced performance on this task cannot be used to distinguish between specific attentional deficits and other cognitive deficits (e.g. speed of information processing) in TBI participants. Digit span (forwards and backwards) was also unable to discriminate between the two groups. This was consistent with the finding of Lezak (1979) who reported Digits Forward scores to be at normal levels at more than three months post-injury. However, a number of other studies have found that Digit Span Backwards remained impaired, even following less severe injuries

(Barth et al., 1989; Uzzell, Langfitt, & Dolinskas, 1987). Thus, the finding of a non-significant difference between the two groups on the Backward Span sub-test, which is thought to be a measure of *supervisory attentional control*, was both contrary to the findings of a number of previous studies and the predictions of the current study.

The Ruff Two's and Seven's Selective Attention Test, although not as widely used as the above-mentioned measures, revealed significant group differences on the Total score, revealing a deficit in *sustained* attention. Cancellation tasks are also thought to provide a measure of *selective* attention, with the Ruff task also enabling a comparison of automatic and controlled attentional processes by calculating separate scores for each of these processes (Ruff et al., 1986). Given the frontal lobe damage often associated with TBI, and the fact that controlled attentional processing is thought to be driven by the frontal lobes (Shallice, 1982), it was hypothesised that there would be a significant difference between the two groups on the controlled task. In contrast, it was predicted that performance on the more automatic task, which is thought to be driven by the posterior regions of the brain, would be unaffected. However, there was a significant difference between the two groups on both the controlled and automatic tasks. In fact, the number of correct responses by the TBI group on the automatic and controlled tasks was identical. This was in contrast to the control group who, consistent with the performance of healthy controls reported in a previous study (Ruff et al., 1992), produced more correct responses under automatic conditions. While this finding of poorer automatic processing by TBI participants was not consistent with the hypothesis, it is consistent with anecdotal reports and clinical observations of TBI participants who appear to require a more controlled approach to what were previously automatic tasks.

Finally, the PASAT revealed significant differences between the two groups across the four timing rates (2.4 sec., 2.0 sec., 1.6 sec. & 1.2 sec.). However, the decline in performance of

TBI participants, as the pacing rates increased, was proportional to the Control group, a finding consistent with Ponsford and Kinsella (1992). Thus, as concluded by Ponsford & Kinsella (1992) it would appear that the differences between the TBI and Control groups on the PASAT were the result of *speed of information processing* rather than specific attentional deficits. This finding is consistent with a number of studies within the literature that have identified a reduced speed of information processing following TBI (Ponsford & Kinsella, 1992; Spikman et al., 1996; van Zomeren, Brouwer & Deelman, 1984). Therefore, the PASAT does not appear to be able to identify specific attentional deficits following severe TBI.

4.8.4.2 Test of Everyday Attention (TEA)

Overall, the results of this study revealed that the severe TBI group performed more poorly on the Map Search, Telephone Search, Visual Elevator (timing score), Elevator Counting with Reversal, and Lottery sub-tests of the TEA. Such a finding is suggestive of deficits in *visual selective attention* (Telephone Search and Map Search), *sustained attention* (Lottery), and *attentional switching* (Visual Elevator), following TBI. While these findings were consistent with those of Robertson et al. (1994,1996), these authors also found an additional difference between the TBI and Control groups on the Telephone Search while Counting (*divided attention*) task. This discrepancy in findings may be explained by the fact that Robertson et al. (1996) used an older TBI group (M = 37.5 years compared to M = 28.9 years), shorter post-injury interval (M=14.6 months compared to M = 28 months), and a smaller sample size (n=15 compared to n=35).

There were also notable differences between the findings of the current study and those of Chan (2000), who found deficits on all but the Elevator Counting sub-test in their TBI participants. However, it must be noted that the Chan (2000) study was based on participants who were complaining of post-concussive symptoms and attentional problems in their daily lives; possibly increasing the likelihood of finding more attentional problems. In addition, the Chan (2000) study used a Cantonese version of the TEA and contained a modified version of the Lottery sub-test. The validity of this version of the TEA has yet to be established.

To summarise, while the Colour-Word, Modified Colour-Word, SDMT, Ruff 2s and 7s Selective Attention Test (total score), and PASAT revealed significant differences between the TBI and Control groups, the limitations of these measures (eg. multi-factorial nature) make it difficult to determine whether reduced performance on these tasks is caused by specific attentional deficits, reduced speed of information processing, or other cognitive deficits. Indeed, all of the tasks that revealed differences between the two groups were *timed* tasks, suggesting that deficits in speed of information processing were making a major contribution to reduced performance on these tasks. Where timing was a less significant component, differences between the two groups were less likely to be found (e.g. Elevator Counting). Of all the measures that were used, only the Visual Elevator sub-test (Accuracy Score) from the TEA and the Forward and Backward Digit Span sub-tests of the WMS-R were free of external time restraints, and none of these showed significant group differences.

4.8.4.3 Relationship between established measures and the TEA

The relationship between the established neuropsychological measures and the TEA sub-tests was examined using correlations. Interestingly, Elevator Counting and Elevator Counting with Distraction did not correlate with any of the established measures of attention, nor did they differ between groups. This was in contrast to two previous studies that have examined correlations between the TEA and conventional neuropsychological tests of attention. For example, Robertson et al. (1996) found a 0.42 correlation between Elevator Counting with Distraction and Backward Digit Span, while Chan et al. (1999) found a significant correlation of 0.38 between Elevator Counting and Backward Digit Span. Of note, however, was that Chan et al. (1999) found that the correlation between Elevator Counting with Distraction and Backward Digit Span was not significant, neither were the correlations between Elevator Counting and the Symbol Digit Modalities Test, or between Elevator Counting with Distraction and the Symbol Digit Modalities Test. It appears that the Elevator Counting and Elevator Counting with Distraction sub-tests may be amongst the least sensitive of the TEA sub-tests, with the current TBI sample producing the same, almost perfect, scores as Control participants on the Elevator Counting sub-test. It should be noted that such an attenuated range of scores in these two sub-tests would contribute to reduced correlations. In contrast, the remaining six TEA sub-tests correlated with the majority of the established measures of attention.

A principal components analysis, which included sub-tests from the TEA as well as other established measures of attention, produced a four factor structure which was largely consistent with the analyses reported by both Robertson et al. (1994, 1996) and Chan et al. (1999). Table 4.8 provides a comparison of the factor structure obtained in these studies. Firstly, there was clear evidence for a factor constituting *visual selective attention.* The second factor (*attentional switching*) contained the Elevator Counting with Reversal sub-test, a task with clear face validity in relation to this factor. However, in contrast to the analyses of Robertson et al. (1996) and Chan et al. (1999), the *attentional switching* factor in the current study did not include the Visual Elevator task. Instead, this Visual Elevator sub-test loaded on the third factor, *sustained attention.* Consistent with the analyses of Chan et al. (2000), the fourth factor (*divided attention*) contained the Telephone Search while Counting Task (dual task decrement) and, as a result, was labeled divided attention. Although this departed from the work of Robertson et al. (1996), who's fourth factor (Elevator Counting with Reversal and Elevator Counting with Distraction) was labeled *auditory-verbal working memory*, it is consistent with the earlier work of Robertson et al. (1994) who originally included the Telephone Search while Counting task as a test of *divided attention.* Furthermore, it is possible that some of the variability in the findings between previous studies (e.g. Robertson et al., 1994; 1996; Chan et al., 1999), and the current study, can be accounted for by the fact that both Robertson et al. (1994) and Chan et al., (1999) only included healthy normal participants in their correlational and principal components analysis, while the current study included both TBI and Control participants.

TABLE 4.8 Comparison of principal components analyses from three separate studies.

Components	**Robertson et al. (1996)**	**Chan et al. (1999)**	**Current study**
Visual Selective Attention	***Map Search*** ***Telephone Search*** ***Stroop*** d2 Cancellation Task	***Map Search*** ***Telephone Search*** ***Stroop*** ***SDMT (oral)*** Elevator Counting with Reversal	***Map Search*** ***Telephone Search*** ***Stroop*** ***SDMT(oral)*** Ruff 2s & 7s Selective Attention Test
Attentional Switching	Visual Elevator (correct) Wisconsin	Visual Elevator (time) ***Elevator Counting with Distraction***	Elevator Counting with Reversal ***Elevator Counting with Distraction***
Sustained Attention	***Lottery*** ***Elevator Counting*** Telephone Search while Counting (dual task decrement)	***Lottery*** ***Elevator Counting*** Backwards Digit Span	***Lottery*** Visual Elevator (correct) ***Backwards Digit Span*** PASAT (2 sec.)
Auditory-Verbal Working Memory	Elevator Counting with Reversal Elevator Counting with Distraction Backwards Digit Span PASAT (2sec.)		
Divided Attention		***Telephone Search while Counting (dual task decrement)***	***Telephone Search while Counting (dual task decrement)*** Elevator Counting

Although there was significant commonality between the principal components analysis in the current study and the findings of Robertson et al. (1994, 1996) and Chan et al. (1999), there were some loadings in the current study that were not consistent with the conceptual nature of these factors. For example, while the Elevator Counting test loaded on the divided attention factor in the current study, conceptually it is more aligned with sustained attention (refer to Table 4.8). In addition, the Visual Elevator (Correct) score, which loaded on the sustained attention factor, could be considered to be more aligned conceptually with attentional switching. It must also be noted that while the battery of tests included in the current principal components analysis were very similar to those included in the analyses of Robertson et al. (1994, 1996) and Chan et al. (1999) there were some notable differences. For example, although the Robertson et al. (1994, 1996) and the current study included the accuracy score on the Visual Elevator sub-test, the Chan et al. (1999) study included the timing score on the Visual Elevator sub-test. As a result of these discrepancies, caution should be used when comparing each of these factor structures.

Finally, a logistic regression was carried out to determine which measure or combination of measures was able to maximally discriminate between the two groups. Of all the sub-tests used in this study, Map Search best discriminated between the two groups. Although this form of analysis has not been carried out within any of the studies reviewed within this chapter, the identification of a brief but efficacious assessment battery has important application in clinical practice, where constraints upon assessment time are often an issue. However, there are also significant disadvantages with such a reductionist approach, as reliance on a restricted range of measures will not provide a sufficiently broad range of tests to cover the components of attention identified within the literature, particularly with regard to providing sufficient information for rehabilitation planning purposes. In addition, while a particular test may not have been able to identify group differences, this does not automatically rule out its clinical utility. The larger standard deviations amongst TBI participants on a number of the sub-tests (e.g. Telephone Search while Counting) provides testament to the sensitivity of these measures in detecting variations in performance following TBI. As both theoretical constructs and factor analyses have identified four components of attentional function, it is suggested that a comprehensive assessment of attention requires a minimum of two sub-tests from each of these factors.

4.8.4.4 Subjective reports of attentional behaviour

When the subjective reports of attentional problems were examined, TBI participants rated themselves no differently to Controls. However, the current study did not specifically select TBI patients who were reporting attentional problems in their everyday life. Nevertheless, the finding of no difference between the Control and TBI group self ratings was in marked contrast to the reports of the significant others who, for the TBI group, provided ratings that were 30% higher than the patients. This finding may reflect a lack of awareness in individuals with TBI (Prigatano & Altman, 1990; Prigatano & Schacter, 1991), and highlights the need to obtain information from a variety of sources. In contrast to the TBI group, the significant-others of the control participants provided ratings 30% lower than the participants, perhaps reflecting an overly self-critical view on the part of the control participants.

An important aspect of the current study was an examination of the relationship between the subjective reports of everyday attentional function (from both TBI patients and their significant others) and clinical measures (i.e. the conventional neuropsychological measures and the TEA). Of the conventional neuropsychological measures, the PASAT (1.6 and 1.2 sec. rate) were the only measures to correlate positively with self-reports of attentional problems. There was also a significant positive correlation between Visual Elevator (Timing Score) and the reports of significant others. Overall, however, there were surprisingly few correlations given the number and range of measures, suggesting that objective and subjective measures of attention are tapping into slightly different processes. Although not highly predictive of test performance, questionnaires provide the clinician with important information regarding areas of concern to the patient.

4.8.4.5 Methodological Issues

When evaluating the findings of the current study, there are a number of issues that should be considered. Firstly, although the TEA provides some tasks that relate more closely to everyday activities, it is still subject to some of the criticisms of existing measures of attention; namely the sub-tests are multifactorial and the test is still presented within a highly structured environment, limiting its ecological validity. The Map Search and Visual Elevator sub-tests, in particular, appear to draw on a range of cognitive processes in addition to attention. However, the introduction of a dual task (Telephone Search while Counting) is an important addition to the range of assessment tools available to the clinician.

The decision to not control for premorbid IQ estimate also warrants further discussion. As noted previously, the results of this study were originally analysed using an estimate of premorbid IQ (NART-R) as a covariate (Bate et al., 2001b). In comparing the two analyses it can be seen that the removal of this covariate resulted in a number of additional significant results (i.e. PASAT -2.4 sec & 2.0 sec. rates, Elevator Counting with Reversal, and Lottery).

4.8.4.6 Summary and Conclusions

This study identified a number of conventional neuropsychological tests and TEA sub-tests that produced significantly different results between the TBI and Control groups [i.e. Map Search, Visual Elevator (timing score), Elevator Counting with Reversal, Telephone Search, Colour-Word, Modified Colour-Word, SDMT (oral & written), Ruff 2's and 7's Selective Attention Test (total score), PASAT (2.4, 2.0, 1.6 & 1.2)]. Consistent with the literature, these differences provided evidence of a *speed of information* deficit amongst TBI participants, as evidenced by their performance on the Stroop and PASAT sub-tests. In addition, the performance of TBI participants on the Ruff 2's and 7's Selective Attention test (total score) and the Lottery sub-test was indicative of a deficit in *sustained* attention. Differences between the TBI and Control groups on the Map Search and Telephone search sub-tests provided evidence for a deficit in visual *selective* attention following TBI, while reduced scores on the Visual Elevator sub-test were suggestive of a deficit in attentional *switching*. The finding of evidence of intact *supervisory attentional control*, as indicated by uncompromised performance on the Digit Span (Backwards) sub-test was contrary to predictions, and the finding of deficit in supervisory attentional control in a number of studies (e.g. Kimonides, 1995; Shallice & Burgess, 1991; Veltman et al, 1996). However, caution should be taken in drawing such a conclusion from the current study as only one measure of this component of attention was used.

A principal components analysis of the sub-tests that revealed differences between the groups identified a factor structure which included *visual selective attention*, *attentional switching*, *sustained attention*, and *auditory-verbal working memory/divided attention*. This factor structure is consistent with previous studies (e.g. Chan et al., 1999; Robertson et al., 1996) and provides a framework, in line with the Posner model, upon which the clinical assessment of attention can be based. While the Map Search sub-test of the TEA was identified as being able to maximally discriminate between the two groups, the importance of devising a clinical assessment protocol that incorporates measures from each of the components of attention must be remembered. It is therefore suggested that any assessment of attention incorporate a minimum of two tests from each of these factors.

With regard to test selection, one of the criticisms of many conventional neuropsychological tests of attention has been that of their poor ecological validity. Thus, the TEA, with its emphasis upon ecologically valid test items, is a welcome addition to the assessment of attention. However, there were surprisingly few correlations between the TEA sub-tests and subjective reports of attentional function following severe TBI.

While the current study has made a number of recommendations regarding which measures should be used in the assessment of attention, the extent to which these measures are able to assess specific attentional functions, independently of other cognitive processes, has been questioned. Many of these measures have been found to be highly multifactorial in nature, involving a number of different cognitive processes. In addition, many of the tests are timed tasks and therefore rely heavily on speed of information processing. Within the current study, all of the tests that revealed differences between the two groups were timed tasks. No differences were found between the groups on the tests that were free of external time constraints. Thus, it appears that the reduced speed of information processing associated with severe TBI makes a significant contribution to performance on attentional tasks. In fact, a number of authors have interpreted this as indicating that there is no evidence of a specific attentional deficit following severe TBI (e.g. Spikman et al., 1996; Ponsford & Kinsella, 1992).

The ability to differentiate between attentional and other cognitive processes in the assessment of attention is therefore a significant challenge to the neuropsychologist. Such information is important in the devising of rehabilitation programs for individuals with attentional difficulties. While it is not suggested that clinicians cease to use the currently available measures, it is important that they are mindful of these limitations when interpreting the results and in making recommendations for the patient. Moreover, it is hoped that the increasing awareness of the limitations of currently available measures of attention will see the development of improved measures of attention. In particular, it is thought that computer generated tasks may well be the most likely means by which attention, speed of information processing and other cognitive processes, can be differentiated.

CHAPTER 5

RECOVERY OF FUNCTION

5.1 Overview

The first four chapters of this thesis have identified a number of deficits in attention following severe TBI. However, little is known about the extent to which there may be any recovery in these deficits over time. This chapter therefore examines the recovery of attentional function following severe TBI.

In recent years, there have been an increasing number of studies devoted to the recovery of function following severe TBI (e.g. Anderson et al., 1996; Asikainen, Kaste, & Sarna, 1998; Gray, 2000; Hillier, Sharpe, & Metzer, 1997; Kersel, Marsh, Havill, & Sleigh, 2001; McMillan & Herbert, 2004; Novack, Alderson, Bush, Meythaler, & Canupp, 2000; Olver, 1995; Page & Levine, 2003; Ponsford, Olver, & Curran, 1995; Ponsford, Olver, Curran, & NG, 1995; Robertson & Murre, 1999; Sbordone, Liter, & Pettler-Jennings, 1995; Seniow, Polanowska, Mandat, & Laudanski, 2003; Spikman, Timmerman, van Zomeren, & Deelman, 1999). These studies have examined recovery of function using a range of measures, including psychometric tests (Bond, 1975; Bond & Brooks, 1976; Spikman et al., 1999) and measures of functional outcome, such as employment status and social re-integration (Asikainen et al., 1998; Ponsford et al., 1995; Sbordone et al., 1995). The current Chapter reviews the literature on recovery of function following TBI, recovery of attention, and the mechanisms by which recovery occurs. Recovery of attention following severe TBI is then investigated in two studies that examine changes to performance on a variety of measures (COAT, standard neuropsychological tests, TEA, questionnaire measures of attentional function) from a cross-sectional (Study 5) and longitudinal (Study 6) perspective.

5.2 Introduction

It is often assumed that recovery in cognitive function following severe TBI occurs mainly within the first 12 months after injury and then tends to plateau within the second year (Bond & Brooks, 1976; Lezak, 1995; Sbordone et al., 1995). One of the earliest studies to report such a finding was Bond (1975), who assessed the cognitive recovery of severe TBI patients who had been referred for neurosurgical treatment. Participants were grouped according to the time since their injury (i.e. 3, 6, 9, 12, 18, and 24 months) and were administered the Wechsler Adult Intelligence Scale (WAIS). The results revealed that participants who had equivalent post-injury intervals produced similar WAIS IQ scores (Bond, 1975). When WAIS IQ scores were compared between the six groups, Bond (1975) concluded that the most rapid recovery occurs within the first six months, followed by a slower rate of improvement that continued steadily for a period and plateaued at 24 months post-injury.

A subsequent study carried out by Bond and Brooks (1976) provided further support for this view. This study incorporated a longitudinal design in which 40 of the participants from the initial study were re-administered the WAIS at 3 months, 4 to 6 months, 7 to 12 months, and more than 13 months post-injury. Bond and Brooks (1976) found that most of the improvement in WAIS scores occurred during the first six months after an injury, with little improvement occurring between six months and two years. Mandelberg (1976) also found that WAIS verbal IQ tended to plateau at around 5 months post-injury, while performance IQ did not reach a plateau until approximately 13 months after a severe TBI. A similar pattern of early recovery, followed by a slower rate of improvement and eventual plateau in recovery, has also been reported for memory function following severe TBI (Levin, Grossman, & Kelly, 1976; Parker & Serrats, 1976).

In addition to these studies of cognitive function, there have been a number of studies of behavioural problems and social re-integration that have found little evidence of recovery beyond 24 months post-injury. Using a structured interview and longitudinal design, Brooks, Campsie, Symington, Beattie, & McKinlay (1986) set out to map the natural history of the consequences of severe TBI at 3 months, 6 months, 12 months, and 5 years post-injury. Relatives of the TBI patients reported limited behavioural and cognitive recovery between 3 months, 6 months, and 12 months post-injury, with high levels of behavioural and cognitive problems still being reported 12 months after the injury. Moreover, at five years post-injury there was little improvement and, in some cases, there was a marked deterioration (Brooks et al., 1986). In a subsequent study, Brooks (1988) compared assessments of psychosocial functioning at the first and fifth year post-injury and found no change in the nature or degree of problems reported by family members. Kaplan (1993) interviewed a group of 25 individuals with severe TBI and their significant others at 12 months, three years, and five years post-injury. He found no evidence of improvements in behavioural and emotional status between the first and third years post-injury, or between the third and fifth years post-injury.

Although there are a number of studies that report a plateau in recovery within 24 months post-injury, a number of authors have challenged these findings. More specifically, they have identified a number of methodological limitations within some of these early studies and have provided evidence of recovery in function well beyond 24 months post-injury. Sbordone and colleagues (Sbordone, 1987, Sbordone et al., 1995), for example, have been particularly critical of the studies by Bond (1975) and Bond and Broooks (1976), arguing that they have significant methodological problems. For example, it has been pointed out that Bond (1975),

(1) did not use a representative sample (i.e. participants had been referred for neurosurgical treatment);

(2) failed to complete serial assessments, basing his conclusions on a single administration of the WAIS;

(3) did not utilise a suitable control group;

(4) failed to include patients who were more than two years post-injury; and

(5) used relatively small numbers within each group (56 participants were divided amongst the 6 groups).

While the second study carried out by Bond and Brooks (1976) addressed one of these issues by using a longitudinal design, they still failed to include a Control group and participants who were more than two years post-injury (Sbordone, 1987, Sbordone et al., 1995). In addition, Sbordone et al. (1995) claimed that the conclusions drawn by Bond and Brooks (1976) were not supported by their data, as a plotting of the data over time revealed serial improvement over the three testing sessions. However, given that Bond and Brooks (1976) did not include a Control group, it is possible that this serial improvement may have reflected practice effects. Despite these criticisms, the work of Bond and Brooks (1975; 1976) is frequently cited and continues to remain influential within the literature.

Spikman et al. (1999) have raised a number of additional methodological issues that often compromise studies investigating recovery of function, including the problem of practice effects, resulting from repeated testing, and the differential sensitivity of tests to various stages of chronicity. Practice effects are largely the result of learning via implicit memory (Spikman et al., 1999), which, according to Spikman et al. (1995) and Vakil et al. (1994), is well preserved following TBI. According to Spikman et al. (1995), it is possible that TBI participants and controls would benefit equally from repeated exposure to the tests. The absence of a control group therefore makes it impossible to gauge the extent of these practice effects and to evaluate recovery of function.

The issue of the differential sensitivity of various measures to recovery is also a significant confound when interpreting test-retest differences (Spikman et al., 1999). A failure to detect differences between initial and re-test scores on a particular measure may not necessarily indicate that no recovery has taken place, rather the measure may not be sufficiently sensitive to detect change (Spikman et al., 1999). The differential sensitivity of various neuropsychological tests can be seen, for example, when comparing test–retest performance on the PASAT, Trail Making Test and the Stroop. While there is evidence for a gradual extended period of recovery on the PASAT, most recovery appears to occur in the first few months post-injury on other tests, such as the Trail Making Test and the Stroop (Spikman et al., 1999). The issue of test sensitivity may well have been a key factor in influencing the findings of Brooks et al. (1975; 1976), who only used the WAIS IQ. It may well be that the WAIS was not sufficiently sensitive to detect recovery of function within these studies. Unfortunately, apart from the work of Spikman et al. (1999), little is known about the differential sensitivity of cognitive tests to recovery of function. As a result, it is critical that any study of the recovery of cognitive function should include a range of measures in order to address this issue.

While the previous studies favour the conclusion that recovery only occurs in the early post-injury interval, there are studies that have reported improvement in function beyond the first two years post-injury. For example, a study by van Zomeren and Deelman (1978) used both simple and choice reaction time tasks, and detected an improvement in reaction time beyond two years post-injury. Najenson et al. (1974) carried out follow-up reviews of participants one to six years after hospital discharge and found significant improvement in motor deficits and, to a lesser extent, cognitive functioning over this time. Significant improvements on neuropsychological measures (i.e. the Reitan-Indiana Neuropsychological Test Battery; Wechsler Intelligence Scale for Children) between the fourth and fifth years post-injury, have also been found in a group of children and adolescents who had suffered a severe TBI (Klonoff, Low, & Clark, 1977). Finally, a study by Thomsen (1984) provided one of the longest follow-up studies within the literature. Participants were visited in their homes and presented with a questionnaire 2½ years after their accident and again at 10 to 15 years after their accident. Questionnaires were also completed by relatives and/or therapists. Of particular note was the fact that patients who could not be left alone 2½ years after their accident became independent during the following years (Thomsen, 1984).

There have also been a number of case studies within the literature that have documented significant recovery of function more than two years post-injury. For example, Sbordone (1984) reported the case of a severe TBI patient who had spent nine months in a coma. This patient received extensive rehabilitation over a number of years and continued to show significant improvement in cognitive functioning, as measured by neuropsychological testing and the reports of significant others, for a period of more than five years post-injury (Sbordone, 1984). Thomsen (1981) also reported the case of a severe TBI patient who demonstrated continual improvement in memory and language for a period of 14 years after their injury. Finally, Workinger and Netsell (1992) reported the case of a TBI patient who regained intelligible speech 13 years after sustaining a severe TBI.

5.2.1 Recovery of Attentional Function

While numerous studies have examined the recovery of cognitive function following severe TBI, very few studies have specifically examined recovery of attention. Moreover, the majority have focussed upon the first two years post-injury, with some studies including TBI groups of mixed injury severity. O'Shaughnessy, Fowler, and Reid (1984), for example, examined the performance of a mild to severe TBI group on the PASAT at one week and again at six months post-injury. At one week post-injury, 89% of participants displayed impaired performance on the PASAT but by six months post-injury this had fallen to 56%. Spikman et al. (1999) administered tests of attention at one, three, six, and 12 months post-injury to participants with severe TBI and controls. Differences in the performance of the control group over these time intervals were thought to indicate practice effects and any improvement in scores beyond those of the control group were attributed to a recovery of attention. The tests administered included the Stroop Colour Word Test, a modified PASAT (Gronwall & Sampson, 1974), the Trail Making Test (Reitan, 1958), the Reaction Time Distraction Task (van Zomeren, 1981), and the Reaction Time Dual Task (van Zomeren, 1981). The severe TBI group performed more poorly than controls on all of the attention measures but their results revealed recovery over time on each of the tests. Unfortunately, Spikman et al. (1999) did not assess participants beyond 12 months post-injury.

Reaction time tasks (both simple and choice) have also been used to assess recovery of attention following severe TBI. Van Zomeren and Deelman (1978) found evidence of an improvement in choice reaction time beyond two years post-injury in a small group of severe TBI participants. This finding lead van Zomeren and Deelman (1978) to call for more research into the recovery of attention beyond two years post-injury.

Thus, there is still considerable debate within the literature regarding the recovery of function following severe TBI. Indeed, some existing research has been hampered by a number of methodological limitations, including a failure to use longitudinal designs and Control groups, and a reliance upon a single or very limited range of measures. In addition, it has been difficult to compare studies because of the variety of measures that have been used. With regard to the recovery of attention following severe TBI, there have been very few longitudinal studies.

Therefore, there is a need for more research investigating the recovery of attention using a broad range of assessment techniques. However, before moving on to such a study, it is important to have an understanding of the processes and mechanisms that may underlie the recovery of function following severe TBI.

5.2.1.1 Processes of Recovery

It is generally agreed within the literature that there are two qualitatively different mechanisms underlying the recovery of function following severe TBI (Bond, 1986; Katz & Mills, 1999; Richardson, 1990). The first of these operates at a neurophysiological level and commences immediately following an injury (Richardson, 1990). The second mechanism, which involves the development of compensatory strategies (behavioural compensation), is dependent upon the patient's awareness of their deficits and, as a result, cannot begin until the resolution of PTA (Humphrey & Oddy, 1980).

Prior to the last decade, it was thought that the spontaneous neurophysiological recovery of human brain function came about solely as a result of a re-organisation of surviving neural circuitary, rather than the restitution of damaged circuitary (Luria, Naydin, Tsvetkova, & Vinarskaya, 1975; Frommer & Smith, 1988). Luria (1963) was the main proponent of this early position, claiming that neurons (apart from those within the hippocampus) do not regenerate and so recovery of function in response to brain injury was thought to be achieved principally by the reorganisation of surviving neural circuits. These compensatory processes, known as 'functional reorganisation' or 'functional adaptation', were thought to result in the same or similar behavioural outcomes being achieved by means of a different neural circuitary. Although there is evidence that this process is an important mechanism in the recovery of function following TBI (e.g. Backman & Dixon, 1992), more recent studies have challenged Luria's assertion that compensatory reorganisation is the only basis for behavioural recovery following brain injury. Robertson and Murre (1999), in their review of the literature, have found evidence that the brain is capable of a large degree of self-repair through synaptic turnover, which refers to ongoing changes in the dendritic branches of neurons and their associated synaptic connections. In other words, there appears to be a rebuilding of the original neural circuits, in addition to the process of using alternate surviving neural circuitary, as proposed by Luria.

While the spontaneous nature of neurophysiological recovery has been demonstrated using various neuro-imaging techniques (e.g. Levin, Amparo, et al., 1987), there is also some evidence to suggest that neurophysiological recovery can also be influenced by external environmental events (Gray, 2000; Kolb, 1995; Seniow, Polanowska, Mandat, & Laudanski, 2003). Even after spontaneous physiological recovery plateaus, the effects of learning, environmental manipulation and psychological factors may have specific neurophysiological effects (Bach-y-Rita, 1992). The notion that environmental experience could influence future learning was first demonstrated by Hebb (1947). Hebb's work lead to a considerable amount of research and debate about whether increased learning ability could be the result of changes in the morphology of neuronal structures, or whether they were the result of learned behavioural compensation strategies. A significant advance in this research came with the development of a technique by Purves and Voyvodic (1987) that was able to track changes in the individual neurons and their connections over intervals of weeks and months in living animals. This technique helped establish that environmental experiences can substantially alter the structure of the cortex (Bach-y-Rita, 2003; Kolb, 1995). Such a finding has significant implications for the design and implementation of rehabilitation programs following severe TBI, particularly with regard to maximising recovery outcomes.

A second key process in the recovery of function following severe TBI is that of behavioural compensation, a process dependent on learning. Compensatory processes can be seen to occur when a given pattern of behaviour is produced by a different set of neuropsychological processes than the processes used by individuals who have not suffered a TBI (behavioural substitution) (Robertson & Murre, 1999). The relearning involved in behavioural compensation can take two forms: (1) relearning a behaviour so that it can be executed in the same way as it was before the injury (behavioural restitution) and (2) producing the same functional outcome (e.g. remembering a person's name) but by using a different behavioural means (e.g. using a prompt card rather than relying on free recall) (Frommer & Smith, 1988). The teaching of behavioural compensation strategies is central to the rehabilitation of individuals following severe TBI (Meier, Strauman, & Thompson, 1987).

The need for clinicians to have an understanding of the neural processes underlying the restitution of brain function has been highlighted by Robertson and Murre (1999), particularly with regard to the selection of the most appropriate rehabilitation strategies to facilitate recovery. Such an understanding is important given the growing body of evidence which suggests that rehabilitation can have significant effects upon the restitution of neural circuitry via synaptic turnover (Robertson & Murre, 1999; Seniow et al., 2003).

Although the content of rehabilitation programs is critical in the optimisation of recovery, the timing of rehabilitation is also a significant issue. Nudo et al. (1996) have shown that brain lesions may result in a loss of synaptic connectivity in neighbouring regions. However, it is possible that this loss could be prevented from becoming more permanent by early intervention (Robertson & Murre, 1999). As a result, it has been suggested that intervention should occur as soon as the patient is medically stable.

While both neurophysiological and behavioural compensation processes contribute to the recovery of function following TBI, the relative contribution of these two processes varies during the course of recovery (Richardson, 1990). For example, in the acute and early post-acute recovery period (i.e. within the first three months of injury), the influence of neurophysiological processes is the greater. However, beyond this period behavioural compensation is likely to make a greater contribution to the recovery of function (Katz & Mills, 1999). One of the main reasons for this variation is that spontaneous neurophysiological recovery has been found to plateau within the first six months following severe TBI (Livingston & Livingston, 1985; Richardson, 1990; Rosenthal & Bond, 1990). In contrast, behavioural compensation strategies, as they are based upon general learning and behavioural principles, continue to develop for a period considerably longer than the 6 months associated with spontaneous neurophysiological recovery (Richardson, 1990).

5.2.2 Summary

Despite significant methodological limitations, early studies of the recovery of function following TBI (e.g. Bond & Brooks, 1975; 1976) have continued to influence research and clinical practice. These studies concluded that the most rapid recovery occurs within the first six months of injury, followed by a slower rate of improvement that continues steadily and plateaus at around 24 months post-injury. However, more recent studies that have addressed some of these methodological limitations have found that recovery of function can occur well beyond this period (Sbordone, 1987; Sbordone et al., 1995; Spikman et al., 1995; 1999). These studies have highlighted the need to use a longitudinal design, a broad range of measures, and a control group. While there have been studies of recovery of function across a range of cognitive and behavioural domains, very few have investigated recovery of attention following severe TBI and most have only examined attention within the first 12 months after injury (e.g. O'Shaughnessy et al., 1984; Spikman et al., 1999). As a result, little is known about the recovery of attentional function beyond two years post-injury. The remainder of this chapter outlines two studies that examine recovery of attention and address some of the limitations of previous research (Study 5 – cross-sectional design; Study 6 – longitudinal design).

5.2.3 Rationale, Aims and Hypotheses for Study 5

The overall aim of Study 5 was to investigate the recovery of attention following severe TBI using a cross-sectional analysis of the data from Studies 1, 2 and 4. However, on those measures where there were no difference between the TBI and Control groups, it follows that there was no recovery to be made. As a result, only those measures that revealed significant differences between the two groups were included in this study. The TBI group within Studies 1, 2 and 4 was made up of 21 participants who were within 12 months of their injury (M = 7.6 months; SD = 3.0) and 14 participants (M = 55.8 months; SD = 33.9) who were more than 24 months post-injury, making it possible to compare these groups (i.e. Early TBI vs Late TBI).

A number of predictions were made regarding the recovery of attention in the Early and Late TBI groups. It was hypothesised that,

Hypothesis 5.1

There would be no difference between the vertical COAT performance of the Early and Late TBI groups.

It was previously noted that recovery of function can result from either neurophysiological processes or behavioural compensation. While much of the recovery within the first 3 months of TBI can be attributed to spontaneous neurophysiological processes, recovery beyond this period is more likely to be the result of behavioural compensation (Katz & Mills, 1999). As the mean time-since-injury for the Early and Late TBI groups was 7.6 months and 55.8 months, respectively, it is likely that any differences in performance between the two groups would largely be due to behavioural compensation. However, as the COAT measures simple reaction times and requires only minimal decision making, it is unlikely to be amenable to behavioural compensation. It was therefore predicted that there would be no differences between the two groups on the vertical COAT.

Hypothesis 5.2

The Late TBI group would perform better than the Early TBI group on the Language task under dual task conditions.

Studies 1 and 2 found that when the Language task was performed under dual task conditions, the TBI group performed more poorly than the Control group. If there are any differences in attention between the Early and Late TBI groups, then this task is likely to detect them. Performance under dual task conditions may also be facilitated by behavioural compensation, which would be better developed in the Late TBI than the Early TBI group.

Hypothesis 5.3

The Late TBI group would perform better on the neuropsychological tests of attention and the TEA.

Unlike the COAT, conventional neuropsychological tests and the TEA appear to be amenable to behavioural compensation and the use of strategies (e.g. using fingers to count the tones on the dual task within the TEA). It is argued that the Late TBI group would have had more time since their injury to develop compensatory strategies, and that they will be more likely to employ these strategies when completing these tasks, resulting in better performance than the Early TBI group.

Hypothesis 5.4

The Late TBI group would report more attentional problems in everyday life than the Early TBI group.

A higher level of self-reported attentional problems (as assessed by the Rating Scale of Attentional Behaviour) in the Late TBI group would result from an increased awareness of their own difficulties and a greater exposure to more complex everyday attentional demands.

Hypothesis 5.5

The significant others of the Late TBI group would report more everyday life attentional problems than the significant others of the Early TBI group.

As many of the Early TBI group were still taking part in rehabilitation at the time of their assessment, they would have been protected in many ways from the attentional demands of everyday life. In contrast, the Late TBI group would have had more exposure to the demands of everyday life and difficulties in coping with some of these demands would have been observed by their significant others.

5.3 Study 5 (Cross-sectional Study)

5.3.1 Method

5.3.1.1 Participants

The data from the 35 TBI participants in Studies 1, 2 (Chapter 3) and 4 (Chapter 4) were re-analysed for this study. For present purposes, the TBI sample was divided into two groups based upon the time since their injury (Early TBI group < 12 months since injury; Late TBI group > 24 months since injury). As the focus of Study 5 was on differences between the Early TBI and Late TBI groups, the Control group data was not included in the analysis. Summary demographic data for the two TBI groups are provided in Table 5.1.

TABLE 5.1 Means and standard deviations for demographic and clinical data for the Early and Late TBI groups in Study 5 (cross-sectional analysis)

	Early TBI *<12 months since injury (n=21)*		***Late TBI*** *>24 months since injury (n=14)*	
Gender				
Male	18		10	
Female	3		4	
Age (years)	26.8	(10.4)	32.0	(12.7)
Education (years)	12.1	(1.4)	11.9	(1.6)
Premorbid IQ Estimate (NART-R)	95.4	(8.6)	95.4	(9.0)
Finger Tapping Speed (preferred-hand)	42.1	(9.8)	43.4	(7.5)
GCS	5.3	(2.8)	6.7	(3.8)
PTA (days)	44.4	(43.4)	40.4	(23.4)
Time Since Injury (days)	235.5	(94.2)	1729.9	(1052.8)

GCS = Glasgow Coma Scale; PTA = Post Traumatic Amnesia

5.3.1.2 Measures and Procedure

The measures analysed in Study 5 were those that revealed significant differences between the TBI and Control groups in Studies 1, 2, and 4. In summary, these tasks were:

Covert Orienting of Attention Task
    Vertical orientation (Single and Dual task presentations)

Language Task (secondary task to COAT) – Single and Dual task presentations from both the horizontal and vertical orientations of the COAT

Conventional Neuropsychological Measures
    Stroop Colour-Word sub-test
    Stroop Modified Colour-Word sub-test
    Symbol Digit Modalities Test (Oral & Written versions)
    Ruff 2s and 7s Selective Attention Test
    Paced Auditory Serial Addition Test (PASAT)
        2.4 sec. presentation rate
        2.0 sec. presentation rate
        1.6 sec. presentation rate
        1.2 sec. presentation rate

Test of Everyday Attention (TEA)
    Map Search
    Visual Elevator
    Elevator Counting with Reversal
    Telephone Search
    Lottery

Rating Scale of Attentional Behaviour
    Self-reports
    Significant Other Reports

As this study was based upon a re-analysis of the data gathered in Studies 1, 2 (Chapter 3), and 4 (Chapter 4), the reader is referred to pages 75 to 78 for a detailed description of the COAT, to pages 154 to 159 for the conventional neuropsychological tasks and TEA, and to page 159 for the Rating Scale of Attentional Behaviour.

5.3.2 Results

5.3.2.1 Matching Variables

The Early TBI and Late TBI groups were found to be comparable in terms of age, years of education, premorbid IQ estimate, and finger tapping speed (refer to Table 5.1). In addition, there were no differences between the two groups in terms of severity of injury (Glasgow Coma Scale, Post-Traumatic Amnesia). As a result, it was not necessary to use any of these variables as covariates in the following analyses.

5.3.2.2 Statistical Analyses

While on the *horizontal* presentation of the COAT (Study 1) there were significant differences between the two groups in overall RTs, the interaction between Group and Cue-Type was not significant. Thus, the two groups were found to orient their attention in a similar way. As a result, only the *vertical* presentation of the COAT, which did reveal a significant Group by Cue-Type interaction, was included in the cross-sectional analysis.

Consistent with Chapter 3, the vertical presentation of the COAT was analysed using a 4-way Group (Early TBI, Late TBI), by Cue-Type (valid, neutral, invalid), by Cue-Target Interval (150, 550, 1000 ms) by Task-Type (single, dual) repeated measures ANOVA. Of interest to the current study was whether there were significant interactions between Group and any of the attentional variables (i.e. cue-type, cue-target interval, task-type), as these would indicate differences in attentional performance between the early and late stages of recovery. *Benefit*, *Cost* and *Validity* effects were also analysed using separate repeated measures ANOVAs. Main and interaction effects that were not specifically related to time since injury are not reported here as they were dealt with previously in Chapters 3 and 4. The COAT Language task (single and dual task), conventional neuropsychological measures, TEA, and the Rating

Scale of Attentional Behaviour were each analysed using a series of univariate ANOVAs. The results of all data analysis can be found within the Appendices in Section 10.0.

5.3.2.3 COAT

5.3.2.3.1 COAT Vertical Presentation (Single and Dual Task)

The vertical presentation of the COAT was analysed using a 4-way repeated measures ANOVA to examine the effects of Group (Early TBI, Late TBI), Cue-Type (valid, neutral, invalid), Cue-Target Interval (150, 550, 1000 ms) and Task-Type (single, dual) on median RTs. Means and standard deviations for the single and dual tasks are provided in Tables 5.2 and 5.3. Before completing this analysis, an examination of the individual participant's data revealed two cases whose scores were consistently greater than 2.8 standard deviations above the group mean[1]. These cases were considered to be outliers and were removed from the analyses. An ANOVA performed on the remaining data revealed that there was not a significant main effect for Group (F(1,31) = 0.12, p = .730, partial η^2 = .004), indicating that there were no overall RT differences between the two groups. The Group by Cue-Type interaction was also not significant (F(2,62) = 2.38, p = .101, partial η^2 = .071) suggesting that both groups orientated their attention in a similar fashion. However, while this interaction was not statistically significant, it equates to a medium effect size. The nature of this Group by Cue-Type interaction is examined more closely in the analysis of *Benefit*, *Cost*, and *Validity* effects below.

There was a significant Group by Cue-Target Interval interaction (F(2,62) = 3.83, p = .027, partial η^2 = .110). Inspection of Tables 5.2 and 5.3 reveals that while the RTs of both groups improved as cue-target interval increased, the Early group showed the greatest improvement

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[1] Early TBI subject (008) produced 13/18 scores that were > 2.8 SD from the Early TBI group mean (with 008 included). Late TBI subject (002) produced 11/18 scores that were > 3 SD from the Late TBI group mean (with 002 included).

in RT. Thus, while the Early and Late TBI groups produced similar RTs at a cue-target interval of 150 ms, the Late Group produced slower RTs at the cue-target intervals of 550 ms and 1000 ms. It appeared that the Early TBI group was able to benefit more, in terms of their overall RT, from increased cue-target intervals than the Late TBI group. This interaction effect is illustrated in Figure 5.1. There were no other significant interactions.

TABLE 5.2 COAT (vertical presentation - single task) data: means and standard deviations of the median reaction times for each of the cue-target intervals

Group	*Cue-Target Interval*	*Valid*	*Neutral*	*Invalid*	*Benefit (Neutral - Valid)*	*Cost (Invalid – Neutral)*	*Validity (Invalid - Valid)*
Early TBI	150 ms	406.3 (62.7)	427.3 (76.9)	416.8 (65.2)	21.0 (23.5)	-10.5 (29.6)	10.5 (18.8)
Late TBI		396.2 (45.5)	420.0 (47.9)	416.7 (50.4)	23.8 (20.5)	-3.3 (23.0)	20.6 (22.7)
Early TBI	550 ms	329.0 (58.6)	340.5 (58.5)	372.4 (63.4)	11.5 (17.1)	31.9 (28.0)	43.4 (28.9)
Late TBI		340.2 (48.3)	342.9 (45.1)	366.5 (58.8)	2.7 (13.5)	23.7 (23.7)	26.3 (26.2)
Early TBI	1000 ms	289.1 (66.3)	309.8 (71.5)	321.3 (83.6)	20.6 (36.9)	11.5 (43.9)	32.1 (34.6)
Late TBI		316.2 (52.2)	323.8 (46.1)	342.9 (55.0)	7.7 (24.5)	19.0 (32.3)	26.7 (34.1)

TABLE 5.3 COAT (vertical presentation - dual task) data: means and standard deviations of the median reaction times for each of the cue-target intervals

Group	*Cue-Target Interval*	*Valid*	*Neutral*	*Invalid*	*Benefit (Neutral - Valid)*	*Cost (Invalid – Neutral)*	*Validity (Invalid - Valid)*
Early TBI	150 ms	410.9 (54.9)	424.1 (56.7)	425.9 (60.2)	13.3 (21.3)	1.8 (25.9)	15.0 (20.8)
Late TBI		407.9 (40.3)	420.8 (43.4)	433.7 (50.7)	12.9 (13.5)	12.9 (17.3)	25.8 (18.3)
Early TBI	550 ms	334.0 (56.1)	350.3 (60.8)	369.0 (72.5)	16.3 (19.7)	18.8 (47.8)	35.0 (44.3)
Late TBI		357.9 (46.3)	376.9 (51.0)	385.8 (46.8)	19.0 (36.9)	8.8 (43.0)	27.9 (26.2)
Early TBI	1000 ms	268.9 (112.8)	298.6 (113.6)	301.3 (138.7)	29.8 (34.9)	2.6 (59.3)	32.4 (43.5)
Late TBI		320.6 (48.4)	332.7 (48.3)	355.8 (43.2)	12.1 (20.0)	23.1 (25.1)	35.2 (29.2)

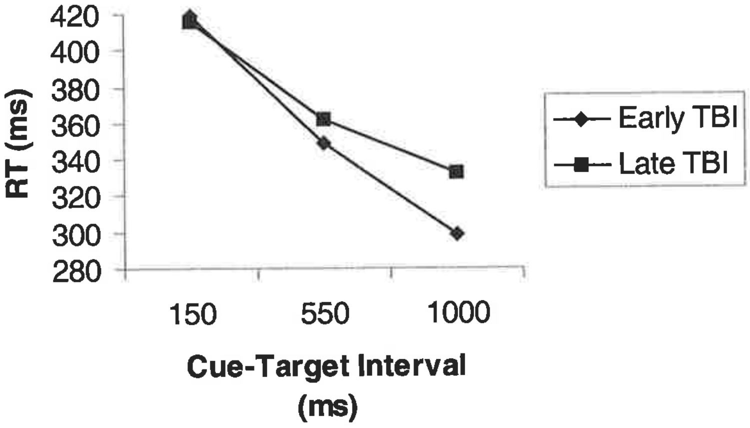

FIGURE 5.1 Mean of median RTs collapsed across invalid, neutral, and invalid cue-types, and across single and dual task conditions

The *Benefit*, *Cost*, and *Validity* effects obtained by both groups are also provided in Tables 5.2 and 5.3. Three separate repeated measures ANOVAs were carried out to examine *Benefit*, *Cost*, and *Validity* effects, respectively, under COAT vertical conditions. There were no significant interactions between Group (Early TBI, Late TBI) and *Benefit* (F(1,33) = 3.10, p = .088, partial η^2 = .086), *Cost* (F(1,33) = 0.04, p = .837, partial η^2 = .001) or *Validity* (F(1,33) = 1.76, p = .194, partial η^2 = .051). However, the effect size for the Group by Benefit interaction indicates that there are moderate differences between the groups with regard to *Benefit*. Examination of Tables 5.2 and 5.3 revealed that the overall *Benefit* displayed by the Late group was less than that of the Early group.

To summarise, there were no overall RT differences between the two groups on the COAT (Vertical). Although both groups produced faster RTs as the cue-target interval increased, it was the Early group that showed most improvement. There were no statistical differences in *Benefit*, *Cost*, or *Validity* effects between the two groups, suggesting similar attentional orienting patterns within the two groups. However, the effect size for the Group by Benefit interaction indicated that the Late group displayed a moderately reduced *Benefit*, compared to the Early group. While the finding of no differences between the groups in terms of *Cost* and *Validity* effects was predicted within Hypothesis 5.1 (i.e. that there would be no difference between the vertical COAT performance of the Early and Late TBI groups), the finding of a difference in *Benefit* between the groups was not. Hypothesis 5.1 was therefore only partially supported.

5.3.2.4 Language Task (horizontal and vertical COAT)

The mean number of errors made on the Language task under both single and dual (i.e. with the COAT) task conditions are reported in Table 5.4. Two repeated measures ANOVAs with

Task-Type (single, dual) as the within subjects factor and Group (Early TBI, Late TBI) as the between subjects factor, were performed on the Language task under COAT horizontal and vertical conditions, respectively. The analysis of the Language task under horizontal COAT conditions revealed a non significant effect for Group (F(1,33) = 0.33, p = .572, partial η^2 = .010) and a non significant Group by Task-Type interaction (F(1,33) = 0.60, p = .443, partial η^2 = .018). Similarly, under vertical COAT conditions, there was a non significant effect for Group (F(1,33) = 0.83, p = .368, partial η^2 = .025) and a non significant Group by Task-Type interaction (F(1,33) = 1.38, p = .248, partial η^2 = .040). Thus, Hypothesis 5.2, which predicted that the Late TBI group would perform better on the Language task under dual task conditions, was not supported.

TABLE 5.4 Mean (and SD) number of errors for both single and dual task conditions for the TBI groups on the Language task.

	Single Task [1]	Dual Task [2] Horizontal Presentation	Dual Task [2] Vertical Presentation
Early TBI (n=21)	0.62 (1.07)	12.05 (10.88)	10.00 (8.72)
Late TBI (n=14)	0.29 (0.47)	14.50 (10.00)	13.36 (10.16)

1. Single task scores represent mean number of errors across 6 lists of 20 words
2. Dual task scores represent the mean number of errors across 30 lists of 20 words.

5.3.2.5 Neuropsychological Measures and the Test of Everyday Attention

Differences between the groups on each of the TEA and conventional neuropsychological assessment measures were examined using a series of univariate ANOVAs. Although the scores of the Late TBI group were higher on virtually all of the conventional neuropsychological measures, none of these differences reached statistical significance (refer to Tables 5.5 and 5.6). However medium effect sizes were apparent for the SDMT (Written), Ruff (Controlled), and Ruff (Total), while a large effect was found for the SDMT (Oral). Thus, there was some support for Hypothesis 5.3, which stated that the Late TBI group would perform better on the neuropsychological tests and the TEA. There was therefore some evidence of recovery on these measures. Tables 5.5 and 5.6 contain the means and standard deviations for each of the attentional measures for both the Early and Late TBI groups.

TABLE 5.5 Means and standard deviations for each of the conventional measures of attention, along with the significance levels and effect sizes of the differences between groups.

	Early TBI (n = 21)		Late TBI (n = 14)			
	M	**SD**	**M**	**SD**	**p**	**partial η^2**
Stroop Colour Word (CW)	35.7	(6.9)	38.6	(10.8)	.342	.028
Modified Colour Word (MCW)	32.8	(7.2)	33.2	(6.0)	.861	.001
SDMT Written Correct	40.2	(9.8)	45.6	(10.8)	.129	.068
Oral Correct	46.6	(11.6)	54.6	(12.0)	.057	.105
Ruff Selective Attention Test Automatic correct	100.0	(25.5)	111.8	(22.6)	.169	.057
Controlled correct	100.2	(22.7)	111.2	(18.1)	.139	.065
Total correct	200.2	(47.7)	223.0	(39.0)	.147	.063
PASAT Total Correct						
2.4	36.0	(11.3)	36.1	(11.5)	.976	.000
2.0	33.2	(11.9)	34.2	(10.0)	.786	.002
1.6	27.9	(6.7)	27.9	(11.7)	.992	.000
1.2	22.0	(8.5)	22.0	(8.5)	1.00	.000

TABLE 5.6 Means and standard deviations for each of the TEA sub-tests, along with the significance levels and effect sizes of the differences between groups.

	Early TBI (n = 21)		Late TBI (n = 14)			
	M	SD	M	SD	p	partial η^2
Map Search	64.1	(13.4)	63.9	(16.0)	.973	.000
Visual Elevator (Time)	4.2	(1.4)	4.3	(1.2)	.790	.002
Elevator Counting with Reversal	7.1	(2.9)	6.6	(3.0)	.683	.006
Telephone Search	3.6	(1.1)	3.5	(1.0)	.662	.006
Lottery	7.9	(1.8)	8.9	(1.5)	.103	.079

5.3.2.6 Self –Significant Other Report

The means and standard deviations for self-reports and significant other reports on the Rating Scale of Attentional Behaviour are displayed in Table 5.7. All of the Early TBI participants returned their forms, while 13 of the 14 Late TBI completed their forms. The return rates for the significant other forms were a little lower, with 17 out of 21 Early TBI and 12 out of 14 Late TBI forms being returned. Univariate ANOVAs were carried out to determine if there were any significant differences between the two TBI groups on either the self-reports or significant other reports. While there were no significant differences between the two groups on the self-report measure ($F(1,32) = 0.38$, $p = .541$, partial $\eta^2 = .012$), there were significant differences between the two groups on the significant other reports ($F(1,27) = 10.36$, $p = .003$, partial $\eta^2 = .277$). The Late group was perceived by their significant others to have significantly more problems with everyday attentional function than were the Early TBI group. Thus, as was predicted in Hypothesis 5.5, it appears that beyond the first year post-injury the significant others of TBI sufferers are likely to perceive more difficulties with everyday attention than in the first year post-injury. However, the prediction of Hypothesis 5.4, that the self-reports of the Late TBI group would exceed those of the Early TBI group, was not supported.

TABLE 5.7 Means (and SD) of both participant and significant other scores on the Rating Scale of Attentional Behaviour for the Early and Late TBI groups.

	Self Report	Significant Other Report
Early TBI	15.0 (9.1)	14.2 (11.3)
Late TBI	16.9 (8.4)	26.4 (8.1)

5.3.2.7 Summary of Cross-Sectional Analysis

This cross-sectional analysis examined differences in performance between the Early and Late TBI groups on a range of attentional tasks that had discriminated between the TBI and Control groups in Studies 1, 2, and 4. It was argued that superior performance by the Late TBI group on any of the attentional tasks may indicate recovery of function beyond the first 12 months post-injury. On the other hand, a failure to find any difference in performance between the two groups may indicate that there is very limited or no recovery beyond 12 months post-injury.

The results of Study 5 revealed that there were no significant differences in overall RTs between the Early and Late TBI groups under vertical COAT conditions, confirming Hypothesis 5.1. However, there was an interaction between Group and Cue-Target Interval. Although both groups were able to reduce their RTs in response to increased cue-target intervals, it was the Early group that was able to take most advantage of increased cue-target intervals. This finding may indicate a decline in performance within the Late TBI group and therefore warrants further investigation.

With regard to specific attentional orienting function, as indexed by *Benefit*, *Cost*, or *Validity* effects, there were no statistically significant differences between the Early and Late TBI groups. However there was a medium effect size for the Group by *Benefit* interaction, indicating some reduced function, at least in relation to *Benefit*, within the Late group. Again this finding provides some evidence of a decline in performance within the Late group. However, any interpretation of this reduced Benefit as a reduction in performance should be considered with reference to the concerns of Jonides and Mack (1984) whose work suggests that the *Validity* effect is a more valid indicator of attentional orienting than *Benefit* or *Cost* scores (refer to Chapter 3). On the Language Task, there were no significant differences between the two groups under single or dual (COAT horizontal and vertical) conditions.

An analysis of the conventional neuropsychological and TEA measures found no statistically significant differences between the Early and Late TBI groups. However, consistent with the predictions of the current study (refer to Hypothesis 5.3), there were medium to large effect sizes between the two groups on two tasks (SDMT, Ruff Selective Attention Test), suggesting that there is some recovery of function in the attentional abilities underlying these tasks beyond 12 months post-injury.

In contrast to the above findings, the Rating Scale of Attentional Behaviour revealed some interesting differences between the groups. While the Early and Late TBI groups perceived their attentional functions to be similar, there were considerable differences between the two groups in the ratings of attention provided by their significant others. Of particular interest was the finding that the significant others of the Late TBI group reported significantly more attentional problems in day to day life than the significant others of the Early TBI group. It appears that, beyond the first year post-injury, the significant others of TBI sufferers are likely to observe more difficulties with attentional function than they would within the first year post injury. However, rather than being an indicator of a decline in function, it is argued that this finding reflects the Late TBI groups exposure to more complex everyday attentional demands.

The cross-sectional method of analysis reported above, while being used in previous studies of recovery of function following TBI (e.g. Bond, 1975; Bond & Brooks, 1976) has been criticised (e.g. Sbordone et al., 1995) because of its failure to assess recovery using a longitudinal design. As a result, Study 6 utilised a 12 month retest/longitudinal design in order to address some of the limitations of a cross-sectional analysis.

5.4 Study 6 (Longitudinal Analysis)

5.4.1 Aims, Rationale and Hypotheses

Using a longitudinal design, Study 6 sought to determine whether the Early or Late TBI group demonstrated any improvement in attention over a 12 month period. The same measures (as used in Study 5) were included in order to maximise the chance of detecting any change. A control group was also re-assessed to provide an indication of the strength of practice effects. Any gains made by the TBI groups, over and above the Control group, were thought to indicate recovery of function.

The hypotheses for Study 6 and rationale for these hypotheses are as follows:

Hypothesis 5.6

Neither the Early or Late TBI groups would display a significant improvement on the COAT task, when compared to Controls.

> Improved performance on the COAT is more likely to result from neurophysiological recovery than from behavioural compensation. As the majority of this neurophysiological recovery is thought to occur within the first 3 to 6 months of injury, it was predicted that there would be no significant improvement in performance in either TBI group.

Hypothesis 5.7

While the Early TBI group would display a significant improvement on the Language task under dual task conditions, the Late TBI group would not.

> When first assessed, the Early TBI group had an average post-injury interval of 8.7 months and were often in the last phase of their rehabilitation. As a result, they were gaining increased exposure to 'real world' situations and were likely to be developing

a repertoire of compensatory strategies to deal with these situations. When re-assessed, it was predicted that the Early TBI participants would have developed compensatory strategies that could be applied to the divided attention (dual) task. However, for the Late TBI group (M = 5.4 years post-injury) the development of compensatory strategies is likely to be reaching a plateau.

Hypothesis 5.8

The Early TBI group would display significant improvements on the majority of neuropsychological measures and the TEA, compared to Controls. However, there would be no such difference between the Late TBI and Control groups.

This hypothesis is based upon the same rationale as was used for Hypothesis 5.7 above.

Hypothesis 5.9

The Early TBI group would report an increase in attentional problems in everyday life

(as assessed by the Rating Scale of Attentional Behaviour).

An increased awareness of problems in the TBI group during the 12 month test-retest period should contribute to this finding.

Hypothesis 5.10

It is predicted that the significant others of the Early TBI group would report more attentional problems in everyday life after a 12 month period.

The significant others of the Early TBI group are likely to observe increased attentional problems in everyday life as TBI participants move from a protected rehabilitation environment into the community.

Hypothesis 5.11

There will be no differences in the test-retest self-report and significant other scores of the Late TBI group.

As the Late TBI group had sustained their injuries some years ago (mean = 5.4 years), it is unlikely that any significant changes would be identified by either the patient's or their significant others, over the 12 month period.

5.4.2 Method and Results

5.4.2.1 Participants

The 70 participants (35 TBI, 35 Control) who took part in Studies 1, 2 (Chapter 3) and 4 (Chapter 4) were invited to return for a 12 month follow-up. Of the original participants, 20 TBI (17 male, 3 female) and 15 Control (7 male, 8 female) participants were re-tested. A change of contact address was the main reason for the loss of participants at follow-up. There were also a few participants from both groups who, because of a change in circumstances (e.g. return to work), were unable to take part in the follow-up testing. When the TBI group were subdivided into Early (< 12 months since injury) and Late (> 24 months since injury) subgroups, there were 11 Early (9 male, 2 female) and 9 Late TBI (8 male, 1 female) participants who were re-tested. While there are relatively low subject numbers within each of these groups, similar subject numbers have been reported in other COAT studies [e.g. 8 patients (Clark et al., 1989); 11 patients, 9 controls (Cremona-Meteyard et al., 1992); 9 patients (Cremona-Meteyard & Geffen, 1994); 10 patients, 10 controls (Danckert et al., 1998); 12 patients (Maruff & Currie, 1995); 13 patients, 7 controls (Posner et al., 1984); 12 patients (Posner et al., 1988)]. Moreover, by calculating effect sizes, it is possible to determine the extent of the group differences independent of sample size (which affects statistical significance). As can be seen in Table 5.8, the mean time since injury at the first assessment for the Early group was approximately 8.7 months, while for the Late group it was approximately 5.4 years.

TABLE 5.8 Means, and standard deviations for demographic and clinical data for the TBI and Control groups.

	Control (n = 15)		Early TBI (n = 11)		Late TBI (n = 9)	
Gender						
Male	7		9		8	
Female	8		2		1	
Age (years)	33.4	(13.0)	30.4	(9.7)	34.3	(15.1)
Education (years)	12.5	(1.9)	12.5	(1.4)	12.3	(1.6)
Premorbid IQ estimate (NART-R)	101.7	(9.2)	97.7	(9.0)	99.9	(4.6)
Finger Tapping (Preferred hand)	49.3	(7.0)	44.3	(12.2)	45.5	(8.4)
Glasgow Coma Scale			5.5	(3.5)	7.3	(4.5)
Post-traumatic amnesia (days)			38.8	(15.7)	38.0	(24.0)
Time since injury - initial assessment (days)			268.8	(71.9)	1970.4	(1130.5)

5.4.2.2 Measures and Procedure

The measures used in Study 6 were the same as those used in Study 5. As with Study 5, the measures chosen for analysis were those that revealed significant differences between the TBI and Control groups in Studies 1, 2, and 4. In summary, these tasks included:

Covert Orienting of Attention Task
    Vertical orientation (Single and Dual task presentations)

Language Task (secondary task to COAT) – Single and Dual task presentations from both the horizontal and vertical orientations of the COAT

- Conventional Neuropsychological Measures
  - Stroop Colour-Word sub-test
  - Stroop Modified Colour-Word sub-test
  - Symbol Digit Modalities Test (Oral and Written versions)
  - Ruff 2s and 7s Selective Attention Test
  - Paced Auditory Serial Addition Test (PASAT)
    - 2.4 sec. presentation rate
    - 2.0 sec. presentation rate
    - 1.6 sec. presentation rate
    - 1.2 sec. presentation rate

- Test of Everyday Attention (TEA)
  - Map Search
  - Visual Elevator
  - Elevator Counting with Reversal
  - Telephone Search
  - Lottery

- Rating Scale of Attentional Behaviour
  - Self-reports
  - Significant Other Reports

The reader is referred to pages 75 to 78 for detailed descriptions of the COAT tasks, to pages 154 to 159 for the conventional neuropsychological tasks and TEA, and to page 159 for the Rating Scale of Attentional Behaviour.

As this study involved repeating the procedures used in Studies 1, 2 (Chapter 3), and 4 (Chapter 4), the reader is referred to pages 81 and 160 within these respective chapters for a detailed discussion of the procedure for collecting this data. Participants were re-tested after a 12 month period (range 12 – 13 months) on an individual basis over four sessions, with each session lasting approximately 120 minutes.

5.4.2.3 Matching Variables

One-way ANOVAs revealed that the Early TBI, Late TBI and Control groups who were followed up had been successfully matched for age, education, estimated premorbid IQ, and finger tapping speed - preferred hand (refer to Appendices). Thus, it was not necessary to use any of these variables as covariates. In addition, the Early and Late TBI groups were matched in terms of injury severity, as there were no significant differences between the two groups on either the Glasgow Coma Scale or the length of Post-traumatic Amnesia (refer to Table 5.8).

5.4.2.4 Statistical Analyses

The vertical COAT data was analysed using a 5-way repeated measures ANOVA to examine the effects of Group (Early TBI, Late TBI, Control), by Cue-Type (valid, neutral, invalid), by Cue-Target Interval (150, 550, 1000 ms), by Task-Type (single, dual), by Time (initial, retest). However, because the independent variable 'Group' contained three levels, it was necessary to carry out further analyses, namely the analysis of simple effects, in order to interpret any Group by Time interaction effects. In keeping with the previous analyses, repeated measures ANOVAs were also carried out in order to assess *Benefit*, *Cost*, and *Validity* effects. Any improvements in the scores of the Control group were considered to reflect practice-effects. Thus, any improvements in the scores of the TBI groups, in excess of this, were thought to indicate recovery of function.

An analysis of test-retest differences on the Language task (under both horizontal and vertical COAT conditions) was carried out using a Group (Early TBI, Late TBI, Control) by Time (initial, retest) repeated measures ANOVA. Interaction effects were further investigated by the analysis of simple effects.

The analysis of the conventional neuropsychological measures, TEA sub-tests, and self/significant other report measures was also carried out via a series of repeated measures ANOVAs and the analysis of simple effects. As the focus of the current analysis was upon retest differences, only analyses relating to the test – retest conditions are reported.

5.4.2.5 COAT Task

5.4.2.5.1 COAT Vertical Presentation

An analysis of the COAT vertical presentation was carried out using a 5-way repeated measures ANOVA to examine the effects of Group (Early TBI, Late TBI, Control), by Cue-Type (valid, neutral, invalid), by Cue-Target Interval (150, 550, 1000 ms), by Task-Type (single, dual), by Time (initial, retest). The means and standard deviations of the median reaction times for each condition and group are provided in Tables 5.9 and 5.10. While there was a significant main effect for Time ($F(1, 31) = 4.73$, $p = .037$, partial $\eta^2 = .132$), there was no significant Group by Time interaction ($F(2,31) = 0.23$, $p = .800$, partial $\eta^2 = .014$). An analysis of simple effects also found no significant differences in Time in the Early TBI ($t(31) = 1.79$, $p = .083$), Late TBI ($t(31) = 0.65$, $p = .522$), and Control groups ($t(31) = 1.50$, $p = .144$). Thus, although there was a significant improvement across all three groups over time, the absence of any interaction effect indicated that this improvement was consistent across the groups. As a result, there was no evidence of improvement in the performance of either of the TBI groups beyond what would be expected from practice effects.

TABLE 5.9 COAT (Vertical – Single Task) data: means and standard deviations of the median reaction times for the three groups.

Group	Cue-Target Interval	Valid (Initial)	Valid (Re-test)	Neutral (Initial)	Neutral (Retest)	Invalid (Initial)	Invalid (Retest)
Early TBI	150 ms	429.3 (109.7)	394.1 (93.6)	445.9 (116.5)	416.4 (111.6)	444.1 (110.6)	413.9 (97.4)
Late TBI		382.5 (45.4)	374.4 (55.4)	406.3 (50.1)	390.3 (46.8)	410.3 (60.2)	401.3 (54.1)
Control		351.8 (58.1)	336.3 (58.4)	367.5 (52.8)	354.2 (50.6)	383.8 (64.2)	362.7 (57.4)
Early TBI	550 ms	357.7 (97.2)	347.0 (127.8)	368.4 (105.2)	354.8 (120.5)	397.3 (106.7)	380.5 (125.2)
Late TBI		330.9 (51.5)	322.5 (55.9)	336.9 (49.9)	335.9 (50.1)	348.4 (62.9)	350.3 (57.1)
Control		289.2 (39.3)	276.3 (32.9)	312.7 (37.3)	299.7 (32.7)	346.5 (50.4)	334.5 (38.5)
Early TBI	1000 ms	315.7 (112.6)	289.1 (117.8)	333.2 (116.1)	311.1 (142.5)	342.5 (129.9)	322.0 (120.8)
Late TBI		304.1 (45.6)	291.3 (51.3)	318.4 (52.3)	298.4 (62.1)	327.5 (60.3)	310.9 (58.4)
Control		263.5 (30.8)	251.0 (22.2)	275.7 (25.6)	268.7 (29.0)	313.5 (32.2)	283.2 (29.2)

TABLE 5.10 COAT (Vertical – Dual Task) data: means and standard deviations of the median reaction times for the three groups.

Group	Cue-Target Interval	Valid (Initial)	Valid (Re-test)	Neutral (Initial)	Neutral (Retest)	Invalid (Initial)	Invalid (Retest)
Early TBI	150 ms	431.1 (77.6)	399.5 (66.2)	454.3 (95.4)	422.3 (84.2)	460.5 (106.4)	422.0 (65.6)
Late TBI		402.2 (31.2)	396.9 (54.9)	416.3 (39.2)	424.7 (68.3)	431.9 (45.5)	409.4 (56.4)
Control		362.5 (57.0)	343.8 (39.7)	380.5 (55.5)	357.7 (32.6)	397.5 (52.2)	366.8 (41.2)
Early TBI	550 ms	358.6 (85.2)	334.3 (67.3)	370.5 (92.1)	353.9 (74.4)	398.4 (110.1)	367.0 (94.7)
Late TBI		353.8 (42.5)	333.1 (56.6)	379.7 (52.3)	359.4 (85.1)	373.4 (39.6)	363.1 (57.6)
Control		303.3 (44.1)	288.5 (34.8)	327.8 (39.1)	303.0 (33.1)	358.7 (51.1)	343.2 (30.4)
Early TBI	1000 ms	298.9 (140.3)	258.2 (136.3)	321.6 (139.0)	294.5 (140.9)	326.1 (173.4)	289.3 (140.6)
Late TBI		311.3 (45.0)	291.6 (58.6)	323.1 (48.6)	324.7 (66.0)	350.6 (48.8)	323.8 (70.3)
Control		276.7 (45.7)	250.8 (38.8)	296.7 (49.8)	276.2 (37.3)	328.7 (51.4)	292.5 (45.2)

Three repeated measures ANOVAs were carried out to examine *Benefit*, *Cost*, and *Validity* effects under COAT vertical conditions. The means and standard deviations of the *Benefit*, *Cost*, and *Validity* effects under both single and dual task conditions can be found in Tables 5.11 and 5.12, respectively. There were no significant interactions between Group or Time and these orienting effects (i.e. Benefit, Cost, or Validity Effect), suggesting that there was no improvement, over and above practice effects, in the attentional orienting of either the Early or Late TBI group, over the one year follow-up period (refer to Appendices). This finding therefore provides support for Hypothesis 5.6 which predicted that neither the Early TBI or Late TBI groups would display a significant improvement on the COAT task, when compared to Controls.

TABLE 5.11 COAT (Vertical – Single task) data: means and standard deviations of Benefit, Cost and Validity effects for each of the three groups.

Group	*Cue-Target Interval*	*Benefit (Initial)*	*Benefit (Re-test)*	*Cost (Initial)*	*Cost (Re-test)*	*Validity (Initial)*	*Validity (Re-test)*
Early TBI	150 ms	16.6 (15.9)	22.3 (25.8)	-1.8 (23.5)	-2.5 (23.3)	14.8 (13.8)	19.8 (20.4)
Late TBI		23.8 (20.7)	15.9 (13.3)	4.1 (24.5)	10.9 (22.6)	27.8 (24.3)	26.9 (20.2)
Control		15.7 (17.2)	17.8 (13.3)	16.3 (24.8)	8.5 (14.0)	32.0 (23.1)	26.3 (15.6)
Early TBI	550 ms	10.7 (22.8)	7.7 (13.3)	28.9 (28.3)	25.7 (21.5)	39.5 (30.5)	33.4 (23.5)
Late TBI		5.9 (12.8)	13.4 (17.3)	11.6 (21.3)	14.4 (27.3)	17.5 (27.1)	27.8 (16.8)
Control		23.5 (18.6)	23.3 (15.1)	33.8 (30.3)	34.8 (26.0)	57.3 (39.5)	58.2 (35.3)
Early TBI	1000 ms	17.5 (20.6)	22.0 (34.6)	9.3 (25.6)	10.9 (40.6)	26.8 (19.5)	33.0 (28.4)
Late TBI		14.4 (21.8)	7.2 (30.5)	9.1 (32.7)	12.5 (31.7)	23.4 (25.2)	19.7 (15.7)
Control		12.2 (12.6)	17.7 (12.5)	37.8 (19.9)	14.5 (32.3)	50.0 (22.5)	32.2 (27.3)

TABLE 5.12 COAT (Vertical – Dual task) data: means and standard deviations of Benefit, Cost and Validity effects for each of the three groups.

Group	*Cue-Target Interval*	*Benefit (Initial)*	*Benefit (Re-test)*	*Cost (Initial)*	*Cost (Re-test)*	*Validity (Initial)*	*Validity (Re-test)*
Early TBI	150 ms	23.2 (29.2)	22.7 (23.7)	6.1 (32.7)	-0.2 (21.7)	29.3 (40.2)	22.5 (12.2)
Late TBI		14.1 (13.7)	27.8 (27.7)	15.6 (19.4)	-15.3 (36.1)	29.7 (19.2)	12.5 (18.0)
Control		18.0 (12.6)	13.8 (16.9)	17.0 (20.2)	9.2 (23.4)	35.0 (19.0)	23.0 (20.8)
Early TBI	550 ms	11.8 (21.9)	19.5 (18.1)	27.9 (41.8)	13.2 (34.4)	39.8 (40.6)	32.7 (44.0)
Late TBI		25.9 (40.1)	26.3 (35.1)	-6.3 (41.8)	3.8 (45.1)	19.7 (22.3)	30.0 (19.6)
Control		24.5 (13.7)	14.5 (18.3)	30.8 (31.6)	40.2 (20.1)	55.3 (31.9)	54.7 (19.5)
Early TBI	1000 ms	22.7 (32.2)	36.4 (37.5)	4.5 (69.6)	-5.2 (48.3)	27.3 (49.0)	31.1 (24.2)
Late TBI		11.9 (22.1)	33.1 (23.4)	27.5 (28.2)	-0.9 (30.2)	39.4 (26.0)	32.2 (23.9)
Control		20.0 (13.6)	25.3 (14.8)	32.0 (20.9)	16.3 (31.4)	52.0 (21.6)	41.7 (24.9)

5.4.2.6 Language Task (Horizontal and Vertical COAT)

Inspection of Table 5.13 reveals that at re-test both the Early and Late TBI groups reduced their number of errors on the Language task. There was no difference between initial and re-test scores for the Control group. In order to determine the significance of these differences, two repeated measures ANOVAs, with Time (initial, retest) as the within subjects factor and Group (Early TBI, Late TBI, Control) as the between subjects factor, were performed on the

Language task under COAT horizontal and vertical conditions, respectively (refer to Table 5.13).

An analysis of the Language task under *horizontal* COAT conditions revealed a significant main effect for Time (F(1,32) = 13.66, p = .001, partial η^2 = .299) and a significant Group by Time interaction (F(2,32) = 4.99, p = .013, partial η^2 = .238). The very large effect size of this interaction indicates the extent of the differences between the three groups in terms of their improvement upon re-test. The analysis of simple effects revealed a significant reduction in errors for the Early TBI (t(32) = 2.04, p = .05) and Late TBI groups (t(32) = 3.94, p = .000), but not for the Control group (t(32) = 0.45, p = .965).

Analysis of the Language task under *vertical* COAT conditions again revealed a significant main effect for Time (F(1,32) = 7.16, p = .012, partial η^2 = .183) and a significant Group by Time interaction (F(2,32) = 3.35, p = .048, partial η^2 = .173). Again this effect size indicates that there were large differences between the three groups in terms of change in scores over the 12 month re-test period. The interaction effect was further examined using a simple effects analysis. Only the Late TBI group revealed a significant difference in errors on the Language task (t(32) = 3.06, p = .004).

TABLE 5.13 Mean (and SD) number of errors on the Language task under dual task conditions for the horizontal and vertical presentations of the COAT for the initial and retest conditions.

	Initial (Horizontal)	*Retest (Horizontal)*	*Initial (Vertical)*	*Retest (Vertical)*
Early TBI (n=11)	8.1 (5.5)	4.6 (3.9)	8.9 (5.6)	6.3 (5.3)
Late TBI (n=9)	18.1 (10.6)	10.6 (6.6)	18.1 (9.5)	11.9 (7.9)
Control (n=15)	4.7 (3.2)	4.8 (5.8)	3.6 (2.5)	4.0 (2.9)

The results of the Language task therefore revealed an improvement in both the Early and Late groups under *horizontal* COAT conditions, and an improvement in the Late TBI group under *vertical* COAT conditions. There was no such improvement in the Control group. While Hypothesis 5.7 predicted an improvement in the Early TBI group on the Language task, it also predicted that there would be no such improvement in the Late TBI group. Thus Hypothesis 5.7 was partially supported.

5.4.2.7 Neuropsychological Measures of Attention and the TEA

The means and standard deviations for each of the established measures of attention and the TEA (i.e. those measures that revealed significant differences between the TBI and Control groups in Study 4) are provided in Table 5.14. Repeated measures ANOVAs were carried out on each of these measures. Interaction effects were investigated by an analysis of simple effects.

Analysis of the Stroop Colour Word test revealed a large and statistically significant effect for Time ($F(1,31) = 22.01$, $p = .000$, partial $\eta^2 = .415$) and a non-significant Group by Time interaction ($F(2,31) = 0.21$, $p = .809$, partial $\eta^2 = .014$). The analysis of simple effects found significant differences between initial and re-test scores for the Early TBI ($t(31) = 2.55$, $p = .016$), Late TBI ($t(31) = 2.83$, $p = .008$), and Control groups ($t(31) = 2.80$, $p = .009$). This improvement in scores across the three groups reflects the large practice effects for this task (refer to Table 5.14).

The analysis of the Stroop Modified Colour Word test found a non-significant effect of Time ($F(1,31) = 0.03$, $p = .859$, partial $\eta^2 = .001$) and a non-significant Group by Time interaction ($F(2,31) = 2.22$, $p = .126$, partial $\eta^2 = .125$). There was, however, a medium effect size for this interaction, indicating that there were moderate differences between the groups in terms of the changes in their scores over time. Further examination of this interaction, via the analysis of simple effects, found no significant differences across time for the Early TBI ($t(31) = 1.11$, $p = .275$), Late TBI ($t(31) = 1.69$, $p = .102$), or Control groups ($t(31) = 0.64$, $p = .524$).

With regard to both the Symbol Digit Oral and Written tests there were no significant effects for Time or Group by Time interactions. An analysis of simple effects also revealed no significant differences (refer to Appendices). Thus, there was no evidence of overall practice effects or any improvement in performance in either of the TBI groups, when compared to Controls, over time.

An analysis of the Ruff (Automatic) scores revealed a significant effect for Time ($F(1,32) = 6.59$, $p = .015$, partial $\eta^2 = .171$) but not a significant Group by Time interaction ($F(2,32) = 1.23$, partial $\eta^2 = .071$). The analysis of simple effects displayed a significant Time effect for the Early TBI group ($t(32) = 2.73$, $p = .010$) but not the Late TBI ($t(32) = 0.48$, $p = .636$) or Control ($t(32) = 1.35$, $p = .188$) groups, indicating an improvement in performance in the

Early TBI group that was not present in the Late TBI or Control groups. Similarly, with regard to Ruff (Controlled) scores, there was a significant effect for Time (F(1,32) = 6.18, p = .018, partial η^2 = .162) but no significant Group by Time interaction (F(2,32) = 0.90, p = .415, partial η^2 = .053). Again, the analysis of simple effects revealed a significant difference over Time for the Early TBI group (t(32) = 2.48, p = .019) but not for the Late TBI (t(32) = 0.464, p = .645) or Control groups (t(32) = 1.50, p = .143). These differences were also reflected in the analysis of the Ruff (Total) score which revealed a significant effect for Time (F(1,32) = 7.14, p = .012, partial η^2 = .182), a non significant Group by Time interaction (F(2,32) = 1.18, p = .320, partial η^2 = .069), and a significant difference across Time, as revealed by the analysis of simple effects, for the Early TBI group (t(32) = 2.75, p = .010), but not the Late TBI (t(32) = 0.50, p = .621) or Control groups (t(32) = 1.50, p = .143). Thus there was evidence of an improvement in the performance of the Early TBI group on each of the Ruff scores. There was no such improvement within the Late TBI or Control groups.

An analysis of the PASAT (2.4 sec. rate) revealed a significant effect for Time (F(1,30) = 20.51 = .000, partial η^2 = .406) but no significant group by Time interaction (F(2,30) = 0.05, p = .952, partial η^2 = .003). The analysis of simple effects found that the Early TBI (t(30) = 2.19, p = .036), Late TBI (t(30) = 2.55, p = .016), and Control groups (t(30) = 3.31, p = .002), each improved significantly over Time, indicating a practice effect on this task (refer to Table 5.14). With regard to the analysis of the PASAT (2.0 second rate) there was also a significant effect for Time (F(1,29) = 11.49, p = .002, partial η^2 = .284) and a non-significant Group by Time interaction (F(2,29) = 0.79, p = .465, partial η^2 = .052). The analysis of simple effects revealed that while both the Early TBI (t(29) = 2.12, p = .042) and Control (t(29) = 3.16, p = .004) groups displayed a significant difference over Time, this was not the case for the Late TBI group t(29) = 0.90, p = .374). Analysis of the PASAT (1.6 sec. rate) revealed a significant effect for Time (F(1,28) = 3.25, p = .082, partial η^2 = .104) and no significant

Group by Time interaction (F(2,28) = 0.32, p = .726, partial η^2 = .023). In addition, analysis of simple effects revealed no significant differences over time within the Early TBI (t(28) = 0.73, p = .469), Late TBI (t(28) = 0.65), or Control (t(32) = 2.05, p = .050) groups, indicating that there was no practice effect on this task. The PASAT (1.2 sec. rate) analysis revealed no significant effects for Time (F(1,28) = 0.36, p = .551, partial η^2 = .013) or Group by Time interaction (F(2,28) = 0.35, p = .707, partial η^2 = .024). There were also no significant findings from the analysis of simple effects within the Early TBI (t(28) = 0.17, p = .864), Late TBI (t(28) = 0.31, p = .763), or Control groups (t(28) = 1.18, p = .247), indicating that there was no overall practice effect or improvement over time in any of the groups on this task also.

With regard to the TEA measures, Map Search revealed a non-significant effect for Time (F(1,31) = .032, p = .859, partial η^2 = .001), and a non-significant Group by Time interaction F(2,31) = 3.24, p = .053, partial η^2 = .173). However, as can be seen, there was a moderate effect size for this interaction. The analysis of simple effects revealed that there was a significant difference over Time for the Control group (t(31) = 2.15, p = .040) but not for the Early (t(31) = 0.97, p = .339) or Late TBI groups (t(31) = 1.03, p = .313). Thus, there was some evidence of a practice effect in the Control group but not in the Early or Late TBI groups, suggesting that the two TBI groups were not able to learn from previous exposure to this task.

Analysis of the Visual Elevator test found a significant effect for Time (F(1,32) = 21.79, p = .000, partial η^2 = .505) but a non-significant Group by Time interaction (F(2,32) = 1.98, p = .154, partial η^2 = .110). The analysis of simple effects revealed significant differences over Time for the Early (t(32) = 2.33, p = .026) and Late TBI groups (t(32) = 3.83, p = .001) but not the Control group (t(32) = 1.70, p = .100). Thus, there was some evidence of improvement over time in the Early and Late TBI groups but not in the Control group. There were no significant differences for Time (F(1,28) = .067, p = .798, partial η^2 = .002) or Group by Time interaction (F(2,28) = 1.18, p = .321, partial η^2 = .078) on the Elevator Counting with Reversal sub-test. An analysis of simple effects also revealed no significant differences across Time for the Early TBI (t(28) = 0.65, p = .523), Late TBI (t(28) = 0.16, p = .873), or Control groups (t(28) = 1.48, p = .150), indicating the absence of practice effects or improvement in performance over time across all three groups on this task.

There was a significant difference for Time (F(1,32) = 11.17, p = .002, partial η^2 = .258), but a non-significant Group by Time interaction (F(2,32) = 2.22, p = .125, partial η^2 = .122) for the Telephone Search task. The analysis of simple effects revealed a significant difference over time for the Early TBI (t(32) = 2.71, p = .011) and Late TBI groups t(32) = 2.45, p = .020) but not for the Control group (t(32) = 0.37, p = .712). Thus, there was some evidence of improvement over time in both of the TBI groups but not the Control group. With regard to the Lottery sub-test, there were no significant Time (F1,32) = 1.50, p = .230, partial η^2 = .045) or Group by Time effects (F(2,32) = 2.08, p = .142, partial η^2 = .115). However, the analysis of simple effects revealed that there was a significant difference in performance over Time for the Late TBI group (t(32) = 2.14, p = .040) but not for the Early TBI (t(32) = 0.65, p = .524) or Control group (t(32) = 0.45) = p = .655).

Thus, the analysis of the standard neuropsychological and TEA measures revealed significant improvement in all three groups on the Stroop Colour Word and PASAT (2.4 sec. rate) tasks. Of particular relevance to the current study, was the significant improvement in scores for both the Early and Late TBI groups (in the absence of any improvement in the Control group) on the Visual Elevator and Telephone Search sub-tests of the TEA. However, inspection of the means in Table 5.14 suggests that some caution should be exercised when interpreting the significant test-retest difference for the Early TBI group on the Visual Elevator task, given the narrow range of scores obtained on this task. There was also a significant improvement in the Early TBI group on the Ruff Selective Attention test but not within the Late TBI or Control groups. In contrast, the Late TBI group produced a significant reduction in performance on the Lottery task, while the other two groups produced no such change. Thus Hypothesis 5.8, which predicted that the Early TBI group would display a significant improvement (compared to the Control group) on the majority of the neuropsychological measures and the TEA, in the absence of any improvement in the Late TBI or Control group, was partially supported. Table 5.15 below summarises the analyses of the standard neuropsychological and TEA measures.

TABLE 5.14 Means, Standard Deviations, for each of the conventional neuropsychological measures of attention and the TEA.

	Control		*Control*		*Early TBI*		*Early TBI*		*Late TBI*		*Late TBI*	
	Initial (n = 15)		*Retest (n = 15)*		*Initial (n = 11)*		*Retest (n = 11)*		*Initial (n = 9)*		*Retest (n = 9)*	
	M	(SD)	M	(SD)	M	(SD)	M	(SD)	M	(SD)	M	(SD)
Stroop												
Colour Word [a]	44.3	(7.2)	49.2	(8.1)	35.0	(7.1)	40.2	(9.6)	36.9	(11.1)	43.6	(11.6)
Modified Colour Word[a]	43.5	(6.8)	46.3	(8.1)	32.2	(7.8)	34.3	(11.1)	32.6	(5.0)	39.4	(11.9)
SDMT												
Written Correct	58.5	(9.6)	61.5	(9.3)	41.0	(10.7)	44.0	(14.3)	45.1	(11.6)	43.9	(9.9)
Oral Correct	70.3	(13.3)	73.2	(14.7)	49.6	(13.2)	52.9	(16.3)	54.2	(12.6)	54.9	(14.6)

[a] Significance levels for these sub-tests were not reported as they are not considered specific tests of attention.

TABLE 5.14 (contd./ d) Means, Standard Deviations, for each of the conventional neuropsychological measures of attention and the TEA.

	Control		*Control*		*Early TBI*		*Early TBI*		*Late TBI*		*Late TBI*	
	Initial *(n = 15)*		***Retest*** *(n = 15)*		***Initial*** *(n = 10)*		***Retest*** *(n = 10)*		***Initial*** *(n = 9)*		***Retest*** *(n = 9)*	
	M	(SD)	M	(SD)	M	(SD)	M	(SD)	M	(SD)	M	(SD)
Ruff 2s and 7s Selective Attention Test												
Automatic correct	130.7	(20.5)	135.3	(20.4)	103.0	(29.7)	113.9	(36.7)	114.8	(23.6)	116.9	(23.0)
Controlled correct	129.6	(18.6)	134.6	(18.6)	102.2	(27.3)	111.8	(34.3)	111.8	(16.1)	113.8	(17.4)
Total correct	260.3	(37.9)	269.9	(37.8)	205.2	(56.8)	225.7	(70.4)	226.6	(38.1)	230.7	(39.3)
PASAT (Total correct)												
2.4	43.0	(11.1)	48.6	(7.4)	39.5	(11.2)	47.2	(10.1)	36.0	(10.3)	41.6	(8.1)
2.0	40.9	(9.4)	45.1	(8.0)	36.5	(12.3)	42.0	(8.3)	34.2	(10.4)	35.8	(9.8)
1.6	35.0	(8.7)	38.3	(9.4)	30.4	(6.4)	34.0	(8.5)	29.8	(11.4)	31.1	(10.1)
1.2	29.3	(6.7)	30.7	(7.2)	24.1	(8.9)	26.3	(7.7)	23.6	(7.8)	24.0	(9.0)

TABLE 5.14 (contd./ d) Means, Standard Deviations, for each of the conventional neuropsychological measures of attention and the TEA.

	Control *Initial* *(n = 15)*		*Control* *Retest* *(n = 15)*		*Early TBI* *Initial* *(n = 10)*		*Early TBI* *Retest* *(n = 10)*		*Late TBI* *Initial* *(n = 9)*		*Late TBI* *Retest* *(n = 9)*	
TEA												
Map search	76.3	(3.7)	71.4	(8.0)	63.8	(15.7)	69.4	(9.0)	60.9	(17.3)	63.9	(9.4)
Visual elevator (Time)	3.0	(0.7)	2.8	(0.6)	3.9	(1.0)	3.6	(0.9)	3.9	(0.6)	3.3	(0.4)
Elevator counting with reversal	8.6	(1.7)	7.9	(1.8)	7.4	(2.7)	7.2	(2.9)	6.7	(3.4)	6.8	(2.9)
Telephone search	2.6	(0.3)	2.5	(0.3)	3.6	(1.4)	3.2	(0.7)	3.5	(0.9)	3.1	(0.7)
Lottery	9.3	(1.2)	9.1	(1.2)	8.1	(1.4)	8.5	(1.6)	9.0	(1.1)	7.8	(2.2)

TABLE 5.15 Significance of the differences between initial and re-test scores for each group on the standard neuropsychological and TEA measures

Test	Early TBI	Late TBI	Control
Stroop Colour Word	*	**	**
Stroop Modified Colour Word	ns	ns	
SDMT (Oral)	ns	ns	
SDMT (Written)	ns	ns	
Ruff (Automatic)	*	ns	
Ruff (Controlled)	*	ns	
Ruff (Total)	*	ns	
PASAT (2.4)	*	*	**
PASAT (2.0)	*	ns	**
PASAT (1.6)	ns	ns	
PASAT (1.2)	ns	ns	
Map Search	ns	ns	*
Visual Elevator	*	**	
Elevator Counting with Reversal	ns	ns	
Telephone Search	*	*	
Lottery	ns	*	

* p<.05; ** p<.01; *** p<.001

5.4.2.8 Self/Significant Other Report

Table 5.16 summarises the means and standard deviations for the self and significant other reports on the Rating Scale of Attentional Behaviour. For the significant other ratings of the TBI group, 15 out of a possible 20 were returned at the initial assessment, and 17 out of a possible 20 upon retest. All of the significant other questionnaires were returned at the initial assessment for the Control group, while 14 out of a possible 15 were returned at the 12 month retest. As a result of these differences, only those participants whose self and significant other questionnaires were returned at both initial and re-test assessment could be included in the analysis ($N_{TBI} = 14$; $N_{Control} = 12$). These results should therefore be interpreted with caution as the Late TBI group, in particular, contained very low subject numbers (n = 5). This may restrict the representativeness of the sample and would limit the statistical power of the analyses.

TABLE 5.16 Means (and SD) on the Rating Scale of Attentional Behaviour at initial assessment and at 12 months retest.

	Self- Report		Significant Other	
	(Initial)	(Re-test)	(Initial)	(Re-test)
Early TBI (n = 9)	17.1 (10.8)	19.7 (14.0)	13.8 (11.3)	17.1 (14.4)
Late TBI (n = 5)	17.6 (6.2)	19.4 (7.1)	26.8 (10.1)	19.2 (12.2)
Control (n = 12)	16.6 (7.3)	17.8 (8.4)	11.1 (7.8)	13.6 (12.7)

The analysis of the self and significant other reports was carried out using two separate Group by Time repeated measures ANOVAs. Interaction effects were examined using an analysis of simple effects. The first ANOVA, which examined Self-Report scores across the three groups, found no significant effect of Time ($F(1,23) = 0.77$, $p = .388$, partial $\eta^2 = .033$) or significant Group by Time interaction $(2,23) = 0.05$, $p = .952$, partial $\eta^2 = .004$). An analysis of simple effects also revealed no significant differences across Time within the Early TBI ($t(23) = 0.77$, $p = .451$), Late TBI ($t(23) = 0.40$, $p = .691$), or Control groups ($t(23) = 0.40$, $p = .690$). Thus, Hypothesis 5.9, which predicted an increase in self reports of attentional problems, was not supported. There was however support for Hypothesis 5.11 which stated that there would be no differences in the test-retest self-report scores of the Late TBI group.

An analysis of the Significant Other scores found no significant effect for either Time ($F(1,23) = 0.11$, $p = .741$, partial $\eta^2 = .005$) or the Group by Time interaction ($F(2,23) = 3.16$, $p = .061$, partial $\eta^2 = .215$). As can be seen however, there was a large effect size for the interaction. A further analysis of this interaction examining simple effects found no significant differences within the Early TBI ($t(23) = 1.19$, $p = .246$), Late TBI ($t(32) = 2.02$, $p = .055$), or Control groups ($t(32) = 1.03$, $p = .313$). As a result Hypothesis 5.10, which stated that the significant others of the Early TBI group would report more attentional problems in everyday life after a 12 month period, was not supported. There was some support for Hypothesis 5.11, which predicted that there would be no differences in the test-retest self-report scores of the Late TBI group. However, this finding should be viewed with some caution. It appears that the large effect size resulted from the fact that although the significant others of the Early TBI and Control group participants both reported slightly increased scores, the significant others of the Late TBI group reported fewer problems after a 12 month interval (refer to Table 5.15). The failure to find statistical significance within this analysis may have resulted from the very small number of participants within the Late TBI group. It should also be noted that the Late TBI group had a substantially higher score than the other two groups at the initial assessment and, despite their improvement over time, their retest score was comparable to the other two groups.

5.4.2.9 Summary of Longitudinal Analyses

The analyses of the COAT vertical data indicated that, while there was a significant improvement in overall RTs over the 12 month period, there were no differences between the groups, suggesting that any improvements were due to practice effects. In addition, there were no differences between the groups in terms of changes in *Benefit*, *Cost*, or *Validity* effects over the 12 month test-retest interval. An analysis of the Language task under both horizontal and vertical dual task COAT conditions revealed that the Late TBI group produced a significantly reduced error rate over the 12 month initial–retest period. This difference was not evident within the Early TBI or Control groups.

The most notable evidence of recovery of function on the standard neuropsychological and TEA tasks was seen on the timed visual selective attention tasks within the TEA (e.g. Visual Elevator, Telephone Search) where significant improvements were seen in the Early and Late TBI groups but not the Control group. In addition, on another timed visual selective attention task, the Ruff 2s and 7s Selective Attention Test, the Early TBI but not the Late TBI or Control group, displayed a significant improvement in performance. The decline in the performance of the Late TBI group on the Lottery subtest suggested that there may be some deterioration in sustained attention more than two years post-injury. There were no changes evident in either the Early TBI or Control group on this task.

The Rating Scale of Attentional Behaviour revealed no increase (or decrease) in self-reported problems across the three groups. Similar results were found when analysing the significant other reports across the three groups. However, the low participant numbers within the Late TBI group made the significant other reports difficult to interpret.

5.5 Discussion

The two studies described in this chapter examined the recovery of attention following severe TBI. The first study (Study 5) used a cross-sectional design involving a re-analysis of the data collected in Studies 1, 2 and 4. Only those measures that revealed significant differences between the TBI and Control groups in these previous studies were included. The TBI sample was divided into two groups, with one group (n = 21) being within the first 12 months of their injury (Early TBI group) and the second group (n = 14) being more than 24 months post-injury (Late TBI group). It was reasoned that, if there were any significant differences between the Early and Late TBI groups, this may suggest that there is some recovery (or deterioration) of attention beyond 12 months post-injury. However, given the limitations of cross-sectional designs reported previously (e.g. Sbordone et al., 1987; 1995), a second study using a longitudinal design (Study 6) was also carried out.

In terms of both experimental and clinical assessment data (i.e. COAT and neuropsychological measures), the cross-sectional analysis suggested that there was no further improvement on these attentional tasks beyond the first year post-injury. However, there was some limited evidence of a deterioration in performance beyond 12 months post-injury. Although there were no differences between the Early and Late TBI groups with regard to how they oriented their attention on the vertical COAT, the Late TBI group were not able to take advantage of longer cue-target intervals to the same extent as the Early TBI group, perhaps reflecting a tendency to be distracted or a deterioration in sustained attention beyond 12 months post-injury.

There were also some differences between the Early and Late TBI groups in terms of the number of attentional problems reported in everyday life. Significant others reported that the

Late TBI group experienced more problems with attention than the Early TBI group. Thus, it is possible that there may be some deterioration in attention beyond 12 months post-injury. However, this finding should be viewed with some caution as there was only very limited evidence of poorer performance by the Late TBI group on the other experimental or clinical measures used in Study 5.

An alternative explanation for the finding that significant others report more problems after longer post-injury intervals is that this may reflect increased exposure to more demanding daily activities. For example, during the first 12 months following a severe TBI, individuals tend not to be exposed to typical everyday attentional demands. Participants may still be involved in outpatient rehabilitation programs and may not have returned to their pre-injury activities. However, by 24 months post-injury, they are more likely to be engaged in employment or study. Those that are not engaged in study or employment may be spending more time around the family home and may be required to take on more responsibilities. As a result, it is likely that they will be exposed to more complex attentional demands than members of the Early TBI group and may be perceived by their significant others as having more difficulty with attention in everyday situations.

Thus, the cross-sectional analyses revealed very limited evidence of differences between TBI sufferers who were in the early and late stages of recovery. Moreover, the differences that were reported would suggest a deterioration in performance and an increase in problems, rather than recovery. Such a finding is consistent with a number of studies that have revealed significant others reporting either no change, or a decline, in cognitive and behavioural function up to 5 years post-injury (Brooks et al., 1986; Brooks, 1988; Kaplan, 1993).

The findings of the longitudinal study (Study 6) also revealed some evidence of change in attention beyond the first year after an injury. In particular, the Late TBI group did produce a significant improvement in performance over a one year period on the Language task under dual task conditions. The robustness of this effect was demonstrated by the fact that it was replicated under both horizontal and vertical COAT conditions. Thus, there may be some improvement in divided attention beyond 24 months post-injury, particularly on language based tasks. However, it should be noted that the initial error rate of the Late TBI group was substantially higher than the Early TBI and Control groups. This difference between the Late and Early TBI groups was not evident in the cross-sectional analysis which included larger participant numbers. This finding therefore requires further investigation using greater participant numbers to determine the sensitivity of this divided attention task to the recovery of function following severe TBI.

With regard to the neuropsychological and TEA measures, there was evidence of improvement in performance between 12 months and 24 months post injury on a number of visual selective attention tests (i.e. Ruff 2s and 7s Selective Attention test, Visual Elevator, Telephone Search), an improvement that was not evident in the Control group. Furthermore this improvement continued to be seen beyond 24 months post injury on two of these three visual selective attention tests (i.e. Visual Elevator, Telephone Search). Conversely, there was a decline in performance in the Late group (in the absence of any significant change in the Early and Control groups) on the Lottery task, suggesting some deterioration in sustained attention beyond 24 months post injury. Thus, while there was some evidence of improvement in visual selective attention and divided attention beyond 2 years post injury, there was also some evidence of a decline in sustained attention.

Although a finding of recovery of function beyond 2 years post injury is not consistent with the earlier work of Bond and Brooks (1975; 1976), it is consistent with more recent studies that have found recovery of function well beyond two years post injury (e.g. Sbordone, 1984; Thomsen, 1981, 1984; Workinger & Netsell, 1992). The finding of a deterioration in sustained attention needs further investigation given the low participant numbers, but may reflect the greater number of problems with attention in everyday life, as perceived by the significant others of TBI sufferers who were more than 24 months post injury (cross-sectional analysis).

While the number of participants in the current studies were in keeping with other TBI studies of attention reported in the literature, there is a need now to investigate the current findings using both a larger number of participants and more 'observation points' during the recovery period (e.g. one, two, three, and five years post-injury). The possibility of multi-centre studies may be one way of ensuring sufficient numbers within such a longer term longitudinal design, where attrition of participants is often a problem.

In conclusion, the two studies reported within this chapter examined the recovery of attentional function following severe TBI, in particular the period beyond 24 months post-injury. The ability to directly compare the findings of a cross-sectional and longitudinal design highlighted the limitations of cross-sectional designs in determining the recovery of function over time. The replication (i.e. under both horizontal and vertical COAT conditions) of an improvement in performance on the Language task (dual task condition), provided evidence of a recovery in divided attention beyond 24 months post-injury. There was also some evidence to suggest an improvement in visual selective attention over this period and a deterioration in sustained attention.

CHAPTER 6

MEMORY AND ATTENTION

6.1 Overview

Memory deficits are a common sequelae to severe TBI. However, the relationship between memory and attention is often overlooked in research and clinical practice. The current chapter briefly reviews the literature regarding the theoretical components of memory and then focuses upon studies that have examined memory function following severe TBI. The relationship between memory and attention is also discussed. Of particular interest is the extent to which deficits in attention may compromise memory function following severe TBI. This question is investigated in Study 7, which forms the basis of this chapter.

6.2 Introduction

Along with attentional problems, memory impairments are one of the most frequently reported and persistent residual deficits following severe TBI (Brooks, Campsie, Symington, & McKinlay, 1986; Levin, 1990; Thone, Zysset, & von Cramon; Schacter & Crovitz, 1977; Shum, Harris, & Gorman, 2000; van Zomeren & Vandenberg, 1985; Wilson, 1991). For example, Brooks (1983) found that 70% of his severe TBI sample reported memory difficulties one year post-injury. At seven years post-injury, 53% of a severe TBI group were still reporting memory problems (Oddy, Coughlan, Tyerman, & Jenkins, 1985). However, the actual incidence rates may be even higher, as people who have suffered a TBI have been found to underestimate the severity of their memory deficits (Baddeley, Sunderland, Watts, and Wilson, 1987; Sunderland, Harris, & Baddeley, 1983). In fact, 79% of the relatives in the Oddy et al. (1985) study reported that people who have sustained a TBI were still experiencing memory problems seven years post-injury, suggesting a tendency to understate their memory problems. Such an understatement is consistent with studies that have reported reduced insight following severe TBI (e.g. Prigatano & Altman, 1990; Prigatano & Schacter, 1991). The pervasive nature of memory impairments following severe TBI and the fact that many people who have suffered a TBI are unaware of the existence or extent of their impairments, has significant implications for rehabilitation and the individual's re-integration back into the community (Glisky & Schacter, 1986; Williamson, Scott, & Adams, 1996). Indeed, Brooks, McKinlay, Beattie, & Campsie (1987) found problems with memory and attention to be the two neurobehavioural sequelae most closely related to unemployment seven years post-injury.

6.2.1 Components of Memory

Memory consists of a number of components or systems (Nissen, 1986; Thone, Zysset, & von Cramon, 1999). Research has found evidence of separate short-term (limited capacity) and long-term (almost infinite capacity) memory systems which are made up of a series of sub-components (refer to Figure 6.1). For example, short-term memory can be divided into immediate memory, which is capable of holding information for just a few seconds (Brown, 1958), and working memory, which can store information for several minutes (Baddeley, 1990; Squire, 1986). Long-term memory, on the other hand, can be divided into declarative, procedural, and prospective memory (Squire, 1986). Declarative or explicit memory is accessible through conscious retrieval processes. It includes facts, episodes, and the lists and routes of everyday life (Squire, 1986). In addition, the memories for facts and episodes have been further classified as semantic and episodic memory, respectively. Semantic memory involves a context independent general knowledge of language, facts, concepts, and rules (Salmon & Butters, 1987; Tulving, 1972; 1985). Episodic memory, on the other hand, is autobiographical in nature and involves the recall of personally experienced events and their temporal relations (Salmon & Butters, 1987).

Procedural or implicit memory involves the memory for procedures and skills, and is not accessible via conscious retrieval processes. As a result, it can only be accessed by engaging in the task in which the knowledge is embedded (Squire, 1986). Procedural memory is therefore determined by performance rather than the conscious awareness of previous events or previously presented information (Baddeley, 1990). Mishkin and Petri (1984) have refereed to procedural memory as a ‘habit system’ that includes many of the routine tasks faced by individuals in their everyday lives.

Evidence that declarative and procedural memory represent quite different memory systems comes from the dissociation between these forms of memory in a number of diagnostic groups (Mitchell, 1989; Schacter, 1987). For example, amnesic patients have shown that they are able to increase their mirror reading skills (procedural memory) at a normal rate over three training sessions and retain this skill level over a three month period (Cohen & Squire, 1980). However, they report no recollection of the training or testing sessions (episodic – declarative memory) or of the specific words that they read.

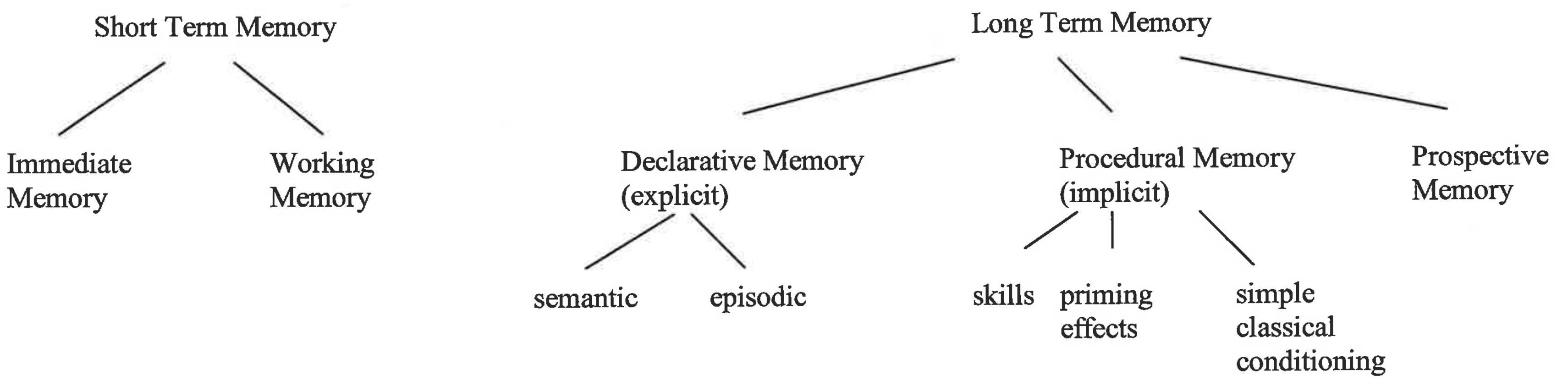

FIGURE 6.1 The components of memory (adapted from Squire, 1986)

A final type of long term memory is that of prospective memory, the memory for future intentions. Prospective memory is concerned with 'when' something should be remembered rather than 'what' should be remembered. As a result, prospective memory tends to have very low information content (Baddeley, 1990). Wilson (1987) suggests that the results of prospective memory assessments are more highly correlated with everyday memory function than are the results of traditional memory tests, which tend to assess aspects of retrospective / declarative memory (i.e. memory for previously presented information or events). In fact, it is likely that prospective memory impairment may be more disabling than retrospective memory impairment (Raskin & Sohlberg, 1996). It has been estimated that 50% - 70% of memory failures in everyday life involve forgetting intentions rather than factual information (Wilson, 1987).

6.2.2 Memory and TBI

Although memory problems are frequently reported following TBI, not all aspects of memory are equally affected (Thone, Zysset, & von Cramon, 1999). With regard to short-term memory, immediate memory (e.g. the immediate recall of digits or words) has been found to be relatively intact following severe TBI (Bennett-Levy, 1984; Brooks, 1975; 1976; 1990; Levin & Goldstein, 1986). However, there is evidence of an impairment in working memory processes, involving the storage and manipulation of information (Baddeley, 1990; McDowell, Whyte, & D'Esposito, 1997).

The ability to recall information after a delay (long-term memory) has also been reported to be severely impaired following severe TBI (Brooks, 1975). For example, deficits have been found in delayed prose recall, paired associate learning, recall of lists, and memory for individual words or pictures (Brooks, 1976; Dikmen, Temkin, McLean, Wyler & Machamer, 1987; Larsson & Ronnberg, 1987). There are a number of mechanisms that are thought to be responsible for these impairments, including an increased susceptibility to interference (Stuss et al., 1985), a more rapid decay of information over time (Squire, 1981), and a selective deficit in the ability to store information in a secondary or long-term store (Brooks, 1976).

Studies that have examined specific components of long-term memory have revealed that not all components are equally affected by severe TBI (Shum, Sweeper, & Murray, 1996). For example, within declarative memory, while semantic memory appears to be maintained (Baddeley, Harris, Sunderland, Watts, & Wilson, 1987), there are significant impairments in episodic memory (Zec et al., 2001). A specific aspect of episodic memory, the memory for the temporal order of events, has also been reported to be disrupted following severe TBI (Shimamura, Janowsky, & Squire, 1991). An individual may be able to recall a particular event but be unable to accurately state when it occurred, suggesting that the contextual information surrounding the event is lost or unavailable (Shimamura et al., 1991).

A second key component of long-term memory (refer to Figure 6.1), procedural memory, has been found to remain relatively intact following TBI (Levin, 1990). Ewert, Levin, Watson, and Kalisky (1989) examined whether a severe TBI group could learn and retain motor skills during PTA, and whether this learning could be transferred to the period following the resolution of PTA. There was significant evidence for preserved procedural memory during PTA, with performance on mirror reading and maze learning tasks improving during this period (Ewert et al., 1989). It has been suggested that procedural (implicit) memory can be utilised to enable people who have sustained a TBI to acquire new skills and information to assist them in their everyday functioning; however they may not remember how or when these skills were learned (Shum et al., 1996).

The third key component of long-term memory, prospective memory, has also been reported to be impaired following severe TBI (Baddeley et al., 1987; Kinsella et al., 1996; Raskin & Sohlberg, 1996). For example, TBI participants have been found to experience difficulty remembering to carry out a particular task, such as requesting a questionnaire at the end of a session, despite being previously primed to do so (Kinsella et al., 1996). However, there is some evidence to suggest that training can improve an individual's prospective memory and that this training can generalise to everyday life (Wilson, 1987).

6.2.3 Post-traumatic, Retrograde, and Anterograde Amnesia following TBI

While the abovementioned research examined memory in terms of the model proposed by Squire (1986), another approach has been to describe memory deficits in relation to the onset of the disorder. This clinical approach categorises the memory deficits following TBI as post-traumatic amnesia (PTA), retrograde amnesia, or anterograde amnesia (Baddeley et al., 1987). Posttraumatic amnesia (PTA) occurs in the early stages following a TBI when an individual is unable to retain information about daily events (Levin, 1990). The duration of PTA can range from a few minutes to many months and its resolution is evidenced by the patient giving "*... a clear and consecutive account of what is happening around him*" (Symonds & Russell, 1943; p 7).

Retrograde amnesia is often a feature in the early stages after a TBI and refers to memory loss for the period prior to the trauma (Nissen, 1986). As such, it represents a form of declarative episodic memory loss (refer to Figure 6.1). The period of retrograde loss usually extends for a number of minutes or hours but, in rare situations, may extend into days and sometimes months (Levin et al. 1985). While this loss is often temporary, Baddeley et al. (1987) have identified a form of retrograde amnesia that lasts for many years post-injury, whereby the individual has either limited or no recall of their personal history. The terms remote or autobiographical memory loss have also been used to describe this retrograde memory loss (Baddeley, 1990; Levin, 1990; Wilson & Moffat, 1992).

The third category of memory disturbance following TBI outlined by Baddeley et al. (1987) is that of anterograde amnesia. Anterograde amnesia refers to problems with new learning and, according to Levin (1990), is the result of increased interference and rapid forgetting. Anterograde amnesia encompasses a number of aspects of memory function discussed previously and, in particular, memory for new information or events that have occurred since the time of injury (e.g. working memory, semantic memory, episodic memory).

6.2.4 The Relationship between Memory and Attention Deficits following TBI

A large number of studies have identified memory deficits following TBI but very few studies have examined the contribution of attentional function to these memory deficits. However, Nissen (1986) suggests that before concluding that an individual has a memory disorder, it is first necessary to consider the possibility that the problem may stem from a failure of attention. The extent to which this relationship has, in the past, been overlooked is reflected in Levin's (1990) review of the literature into memory deficits following TBI. This review made no mention of a relationship between memory and attention, apart from noting that attention was one of a number of behavioural disturbances associated with PTA.

Although the contribution of attention to memory function has, in many instances, been neglected by both researchers and clinicians, interactive models of memory have started to examine the relationship between attention and memory. Such a relationship can be seen within the Working Memory model of Baddeley (1966), with both attention and memory being involved in the simultaneous processes of short-term storage and the manipulation of information. Atkinson and Shiffrin (1968) have also acknowledged the relationship between memory and attention, stating that attention is necessary for controlling the selection of information both into and out of short-term and long-term memory. In addition, Cowan (1988) notes that, while the contribution of attention to memory function is gaining greater recognition, there is also a paradoxical relationship between memory and attention, with attention depending upon the comparison of new information with existing templates within memory. Thus, existing memory representations influence efforts to seek information and meaning from the environment and, as a result, influence the direction and focus of attention (Cowan, 1988; Nissen, 1986).

Of the studies that have examined the relationship between attention and memory following severe TBI, most have used a dual task paradigm. Here, participants are instructed to attend to one task or stimuli while ignoring the other (Nissen, 1986). Recall or recognition of the unattended information has been found to be particularly poor (Nissen, 1986; Nissen & Bullemer, 1987), indicating the important contribution of attention to short term memory. Mangels, Craik, Levine, Schwartz, and Stuss (2000) also reported that when items were encoded into memory under divided attention (dual task) conditions, TBI participants displayed significant deficits, suggesting that memory impairment following TBI may well be secondary to impairments in attention. This was in marked contrast to the finding that there were no differences between TBI and Control participants when items were encoded under focussed attention (single task) conditions (Mangels et al., 2000).

The relationship between memory and attention has also been investigated following TBI by examining the correlations between the Attention/Concentration Index score and the four memory Index scores of the WMS-R (Verbal Memory, Visual Memory, General Memory, Delayed Memory) (Reid & Kelly, 1993). Significant correlations were found between the Attention/Concentration Index and the General Memory and Verbal Memory Indices, suggesting that attention may contribute to the memory performance of TBI patients (Reid & Kelly, 1993). However, this finding should be viewed with some caution given the concerns that have been raised regarding the Validity of the Attention/Concentration Index (e.g. Crossen & Wiens, 1988; Franzen & Iverson, 2000; Johnstone, Erdal, & Stadler, 1995). For example, while the Attention/Concentration Index has been found to be a highly sensitive measure in identifying cognitive impairment, and highly related to measures of memory, it is not correlated with other independent measures of attention (Johnstone, Erdal & Stadler, 1995).

6.2.5 Summary

The model of memory, as described by Squire (1986) (refer to Figure 6.1), provides a useful framework for the examination of memory function following severe TBI. Such an examination reveals that while immediate memory appears to be intact following severe TBI, there is evidence of impairment in working memory processes (Levin & Goldstein, 1986; McDowell et al., 1997). Furthermore, although episodic and prospective memory processes are also impaired, semantic and procedural memory processes are relatively well preserved (Baddeley et al., 1987; Levin, 1990; Zec et al., 2001). Surprisingly, although both memory and attention problems are a significant sequelae to severe TBI (e.g. Brooks et al., 1986; Levin, 1990; Wilson, 1991), very few studies have examined the relationship between attention and memory (Reid & Kelly, 1993), and only a very limited range of measures have been used. There is therefore a need to examine the relationship between attention and memory following severe TBI using a broader range of measures.

6.2.6 Aims and Hypotheses

The overall aim of this study was to examine memory deficits following severe TBI, and the relationship between memory performance (WMS-R) and various measures of attention (i.e.

Attention/Concentration Index of the WMS-R, and the Map Search, Elevator Counting with Reversal, and Lottery sub-tests of the TEA). The specific aims of this study were as follows.

Aim 1

To determine whether there were any differences between TBI and Control participants on the sub-test and Index scores of the WMS-R[1].

Hypothesis 6.1

It was hypothesised that TBI participants would display deficits on all of the WMS-R sub-tests, except for the Forward Digit Span sub-test, when compared to Controls.

The Forward Digit Span sub-test is considered to be a test of immediate memory and has been found to be relatively intact following severe TBI.

In addition, it was hypothesised that TBI participants would display deficits on each of the WMS-R Index scores.

Aim 2

To examine the relationship between memory performance (as indexed by the Verbal, Visual, General, and Delayed Index scores) and attention (as indexed by the Attention/Concentration Index score) within the TBI group.

Hypothesis 6.2

It was predicted that there would be significant correlations between the Attention/Concentration Index and each of the other WMS-R Index scores.

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[1] data collection for the current study commenced in 1996 and so the author was not able to use the more recently published Wechsler Memory Scale-III (Wechsler, 1997).

Aim 3

To determine whether any differences in memory performance between the two groups could be accounted for by attentional deficits.

Hypothesis 6.3

It was hypothesised that the inclusion of a range of attentional measures (i.e. Map Search, Elevator Counting with Reversal, Lottery) as covariates in the separate ANOVAs would remove any significant differences between the two groups on the WMS-R scores.

It was decided to select these TEA measures as covariates as they revealed significant differences between TBI and Control groups in an earlier analysis (refer to Chapter 4).

6.3 Study 7

6.3.1 Method

6.3.1.1 Participants

Thirty three of the severe TBI participants and 35 controls who were described in Study 4 (Chapter 4) were included in this study. Two of the original 35 TBI participants had been administered the memory measure for clinical purposes three months prior to this study and so were not included in this part of the study (i.e. to avoid practice effects caused by re-testing). Demographic and clinical data for the two groups are displayed in Table 6.1.

TABLE 6.1 Means and standard deviations for the demographic and injury variables for the TBI and Control groups

	TBI (n = 33)		Control (n = 35)	
Gender				
Male	27		20	
Female	6		15	
Age	28.9	(11.4)	30.2	(10.3)
Education	12.0	(1.5)	12.6	(2.0)
Premorbid IQ estimate (NART-R)	95.4	(8.7)	101.1	(9.1)
Glasgow Coma Scale	5.6	(3.1)		
Post-traumatic amnesia (days)	43.6	(39.6)		
Time since injury (days)	869.3	(1009.1)		

6.3.1.2 Measures

Attentional Measures

The attentional measures included in the current study were selected from those that revealed significant differences between the TBI and Control groups in Study 4 (Chapter 4). As many of these attentional measures correlated highly with one another (e.g. refer to Table 4.4), care was taken to limit the number of measures in the current analysis. In addition, selection was based on providing a group of measures that best represented the factor structure of attention identified in Chapter 4. Thus, in line with these criteria, the *Map Search* (representing visual selective attention), *Elevator Counting with Reversal* (representing attentional switching) and *Lottery* (representing sustained attention) sub-tests were included in the current study. The reader is referred to Chapter 4 (pages 157 - 159) for detailed descriptions of these measures.

Memory Measures

Wechsler Memory Scale – Revised (WMS-R) (Wechsler, 1981)

The WMS-R is comprised of 13 sub-tests and takes between 45 and 60 minutes to administer. The *Information and Orientation* sub-test was not administered in the current study as it does not contribute to any of the Index scores that are calculated from these measures. The remaining 12 sub-tests are outlined below. The tests that are used to calculate the five Index scores are provided in Table 6.2.

TABLE 6.2 WMS-R sub-tests and corresponding Index scores

			WMS-R	**Index**	
	Verbal Memory	Visual Memory	General Memory	Attention/ Concentration	Delayed Memory
Mental Control				x	
Figural Memory		x	x		
Logical Memory I	x		x		
Visual Paired Associates I		x	x		
Verbal Paired Associates I	x		x		
Visual Reproduction I		x	x		
Digit Span				x	
Visual Memory Span				x	
Logical Memory II					x
Visual Paired Associates II					x
Verbal Paired Associates II					x
Visual Reproduction II					x

Mental Control

This sub-test requires the person to count backwards from 20 to zero within 30 seconds, recite the alphabet within 30 seconds, and count by 3s from 1 to 40 within 45 seconds A maximum of two points can be obtained for each of these parts. The score is reduced to one point if an error is made, with no credit given for two or more errors (range = 0 to 6).

Figural Memory

On this sub-test, the person is presented with an abstract design and then asked to identify that design from a range of similar designs. There are four trials within this sub-test. In the first trial, the person is presented with a design for five seconds and then asked to identify this design within an array of three designs. In the remaining three trials, the person is presented with three designs for 15 seconds and then asked to identify these three designs from a choice of nine designs. The score for this sub-test is therefore the total number of designs correctly identified (scoring range = 0 to 10).

Logical Memory 1

Two short stories are read to the participant, with immediate free recall being tested after each story. Both stories contain 25 'ideas' or scoring units, with one point being given for each correctly recalled unit (scoring range = 0 to 50).

Visual Paired Associates 1

The participant is shown a series of six abstract line drawings, each of which are paired with a different colour. Three recall trials are then presented, with each design being shown for 3 seconds. In each trial, the participant is presented with the six designs (in a different order to the original presentation) and asked to name the colour that is associated with it. One point is given for each correct response (scoring range = 0 to 18).

Verbal Paired Associates 1

The participant is read a list of eight word pairs, with four of the pairs forming common or 'easy' associations (e.g. baby-cries), and the remaining four pairs forming uncommon associations (e.g. cabbage – pen). The list of word pairs is read three times. After each presentation, the participant is read the first word of each of these pairs and is asked to recall the associated word. One point is given for each correct response (scoring range = 0 to 24).

Visual Reproduction 1

This sub-test involves the individual presentation of four geometric designs. After a period of 10 seconds, the design is removed and the participant is asked to draw the design from memory. A detailed scoring protocol for each item is outlined in the test manual (maximum score = 41).

Digit Span

There are two parts to the Digit Span sub-test, Digits Forward and Digits Backward. In Digits Forward, the examiner reads aloud a series of number sequences of increasing length. The participant's task is to repeat each sequence exactly as it is given. In Digits Backward, the examiner again reads aloud a series of number sequences of increasing length, which the participant must repeat backwards. One point is given for each response. Scores on the forward and backward components of this task are summed to provide a Total Score (maximum score = 24).

Visual Memory Span

The Visual Memory Span sub-test is a visual analogue of Digit Span. As with Digit Span, there are two parts to this sub-test, Tapping Forward and Tapping Backward. In the Tapping Forward task, the examiner taps a series of printed red squares in a predetermined sequence. The subject is then required to tap the sequence in the same order. Two trials are presented at each of seven sequence lengths (score range = 0 to 14). Tapping Backward involves the same administration and scoring procedure as Tapping Forward, except that participants are required to tap the squares in the reverse order to the examiner. A Total Score is calculated from the Forward and Backward scores (scoring range = 0 to 26).

Logical Memory 2

Participant's recall of the two Logical Memory passages is tested approximately 30 minutes after the original presentation. The scoring protocol is the same as that used for Logical Memory 1 (maximum score = 25).

Visual Paired Associates 2

Thirty minutes after the presentation of Visual Reproduction 1, the participant is again presented with the same six line drawings and asked to name the colour that is associated with it. One point is given for each correct response (scoring range = 0 to 6).

Verbal Paired Associates 2

A single recall trial of the word pairs presented in Verbal Paired Associates 1 is administered approximately 30 minutes after the original presentation. One point is given for each correct response (scoring range = 0 to 8).

Visual Reproduction 2

The participant is required to draw from memory the four designs presented in Visual Reproduction 1 thirty minutes after the original presentation. The same scoring protocol as used in Visual Reproduction 1 is utilised (maximum score = 41).

6.3.1.3 Procedure

The data was gathered as part of a larger study investigating deficits in attention following severe TBI (refer to Studies 1 to 4). The presentation of the measures of attention and the WMS-R were counterbalanced, over two sessions, to control for any effects of order. As this study was based largely upon data gathered in Study 4 (Chapter 4), the reader is referred to page 160 for a more detailed discussion of the procedure for collecting this data.

6.3.2 Results

6.3.2.1 Matching Variables

One-way ANOVAs revealed that although the TBI and Control Groups had been successfully matched for age and education, there was a significant difference between the two groups in estimated premorbid IQ ($F(1,68) = 7.15$, $p = .009$, partial $\eta^2 = .095$) (refer to Table 6.1). However, for the reasons outlined for the previous studies, it was decided not to include estimated premorbid IQ as a covariate.

6.3.2.2 Statistical Analyses

Univariate F ratios were calculated for each of the WMS-R sub-tests and Index scores in order to determine whether there were differences between the TBI and Control groups (Aim 1). Correlations between the Attention/Concentration Index and each of the memory Index scores were calculated to examine the relationship between attention and memory (Aim 2). In order to determine whether the memory differences between the two groups could be accounted for by attentional deficits (Aim 3), a number of sub-tests of attention (Map Search, Elevator Counting with Reversal, and Lottery) were entered as covariates into a series of Group by Memory Index (i.e. Verbal, Visual, General, and Delayed Index scores) ANOVAs. All data were analysed using SPSS version 11.5 (SPSS, 2002).

6.3.2.3 Group differences on WMS-R sub-test and Index scores

Means and standard deviations for the TBI and Control groups for each of the sub-tests of the WMS-R are provided in Table 6.3. As can be seen from Table 6.3 there were significant differences between the two groups on all but the Mental Control, Forward Digit Span, Backward Digit Span, and Visual Memory Span sub-tests of the WMS-R. Thus, Hypothesis 6.1, which predicted significant differences between the two groups on all but the Forward Digit Span sub-test, was only partially supported.

TABLE 6.3 Means, standard deviations (and significance levels) for the WMS-R sub-tests.

	TBI		Control		sig	partial η^2
Mental Control	5.6	(0.7)	5.5	(0.8)		.000
Figural Memory	6.7	(1.8)	8.0	(1.5)	**	.142
Logical Memory 1	22.9	(7.1)	26.9	(6.0)	*	.084
Visual Paired Associates 1	12.2	(4.2)	14.7	(2.9)	**	.110
Verbal Paired Associates 1	17.4	(3.4)	19.5	(4.1)	*	.073
Visual Reproduction 1	37.1	(3.1)	38.9	(2.6)	**	.098
Forward Digit Span	6.4	(1.1)	6.8	(1.1)		.038
Backward Digit Span	4.9	(1.1)	5.4	(1.2)		.046
Visual Memory Span	17.4	(3.3)	17.9	(3.1)		.008
Logical Memory 2	16.6	(8.7)	23.0	(6.0)	**	.158
Visual Paired Associates 2	4.9	(1.2)	5.8	(0.7)	**	.155
Verbal Paired Associates 2	6.4	(1.7)	7.3	(1.4)	*	.079
Visual Reproduction 2	29.6	(10.2)	35.9	(6.0)	**	.129

*p<.05 **p<.01 ***p<.001

Means and standard deviations for the TBI and Control groups for each of the five WMS-R Index scores are provided in Table 6.4. As can be seen from Table 6.4, significant differences were found between the two groups on the Verbal, Visual, General, and Delayed Memory

Index scores, thus providing further confirmation for Hypothesis 6.1. However, contrary to Hypothesis 6.1, there was no significant difference between the two groups on the Attention/Concentration Index.

TABLE 6.4 Means, standard deviations (and significance levels) for the WMS-R index scores

	TBI		Controls		sig	partial η^2
Verbal Memory	90.5	(16.4)	100.0	(13.7)	*	.092
Visual Memory	102.7	(14.7)	116.3	(14.3)	***	.186
General Memory	93.1	(17.9)	105.4	(15.0)	**	.127
Attention/ Concentration Index	97.2	(17.1)	103.8	(14.4)		.044
Delayed Memory	89.5	(22.2)	109.6	(15.5)	***	.224

*p<.05 **p<.01 ***p<.001

6.3.2.4 The relationship between WMS-R Memory and Attention/Concentration Indices

Consistent with the methodology of Reid and Kelly (1993), correlations between the Attention/Concentration Index and each of the four memory indices were calculated for the TBI group. There were moderate and significant correlations between the Attention/Concentration Index and each of these Index scores (refer to Table 6.5), suggesting attentional skills were related to memory performance. Thus, Hypothesis 6.2 was supported. However, the finding above of a non-significant difference between the two groups on the Attention/Concentration Index makes the interpretation of this finding less clear. This issue will be examined in more detail in the Discussion section below.

TABLE 6.5 Correlation between the Attention/Concentration Index and the WMS-R Indices, with the TBI and Control groups combined.

WMS-R Index	r	p
Verbal Memory	.53	.001
Visual Memory	.40	.017
General Memory	.58	.000
Delayed Memory	.51	.002

The relationship between attention and memory was further examined by repeating the same series of Group by WMS-R Memory Index ANOVAs reported above but this time including three attentional measures as covariates (i.e. Map Search, Elevator Counting with Reversal, & Lottery). When these covariates were included in the analysis, the differences between the two groups on the Verbal Index ($F(1,55) = 0.55$, $p = .461$, partial $\eta^2 = .010$), Visual Index ($F(1,55) = 3.26$, $p = .076$, partial $\eta^2 = .056$), General Memory Index ($F(1,55) = 0.83$, $p = .365$, partial $\eta^2 = .015$), and Delayed Index scores ($F(1,55) = 1.37$, $p = .247$, partial $\eta^2 = .024$) were no longer significant (refer to Table 6.4). Hypothesis 6.3, which predicted that the inclusion of the attentional measures as covariates would remove any significant differences between the two groups on the WMS-R Index scores, was therefore confirmed. Thus, it appears that the deficits in memory performance (on the WMS-R) of people who have sustained a severe TBI can be explained in terms of an attentional impairment, or at least something that is assessed by attentional measures (e.g. speed of information processing), rather than memory impairment.

6.3.3 Discussion

This study compared the memory function of TBI and Control participants, as measured by the WMS-R. The main aim of the study was to determine whether deficits in memory could be accounted for by attentional impairment. In terms of performance on the WMS-R sub-tests, there were no significant differences between the two groups on Mental Control, Forward Digit Span, Backward Digit Span, and Visual Memory Span. The comparable performance of the two groups on the Forward Digit Span and Visual Memory Span sub-tests, which are both considered tests of immediate (short-term) memory, was consistent with the preserved immediate memory of TBI sufferers reported within the literature (Bennett-Levy, 1984; Levin & Goldstein, 1986). In addition, TBI participants performed at a significantly lower level than Controls on the Logical Memory 2, Visual Paired Associates 2, and Visual Reproduction 2 sub-tests. Each of these sub-tests are considered tests of long-term memory. Deficits in long-term memory following severe TBI have been consistently reported within the literature (Brooks, 1975; 1976; Levin, 1990).

The differences between the TBI and Control groups on the WMS-R sub-test scores were also reflected in the associated Index scores. TBI participants were significantly impaired, compared to Controls, on the WMS-R General, Verbal, Visual, and Delayed Memory Index scores. However, the failure to find group differences on the Attention/Concentration Index score was not consistent with the results of Reid and Kelly (1993), who reported significant differences between TBI and Control groups on all five Index scores.

There are two possible reasons for the differences between the results of the current study and those of Reid and Kelly (1993). Firstly, with the exception of one subject, all of the TBI participants in the Reid and Kelly (1993) study were between one and three months post-injury, compared to an average of 29 months in the current study. Thus, the TBI participants in the Reid and Kelly (1993) study were still within the acute or post-acute stages of recovery and therefore, unlike the participants in the current study, had not had the benefit of an extended recovery period.

Secondly, while the finding that there was no significant difference between the TBI and Control groups on the Attention/Concentration Index was surprising, Crossen and Wiens (1988) found that the tests constituting the Attention/Concentration Index of the WMS-R did not require the same focussed or sustained effort as many other tests of attention. In addition, the sub-tests within the Attention/Concentration Index were not able to produce the same 'attentional overload' as many other attentional measures (Crossen & Wiens, 1988). As a result, the validity of the Attention/Concentration Index has been questioned (Crossen & Weins, 1988; Franzen & Iverson, 2000).

The relationship between attention and memory following TBI was initially examined in this study by calculating the correlations between the Attention/Concentration Index and each of the other WMS-R Index scores. Significant correlations were found between the Attention/Concentration Index and the other Index scores of the TBI group, suggesting that attention is related to memory performance. However, as the relationship between memory and attention has previously been investigated using only a very limited range of measures (e.g. the attention/concentration measures from within the WMS-R), a slightly broader range of measures was examined in the current study. The three attentional measures that were selected were those that had been found to differentiate between severe TBI and Control participants in Study 4, and were also representative of the attentional factors/components identified within the principal components analysis in Chapter 4. When these attentional measures were included as covariates within the WMS-R analysis, there were no group differences on the General, Verbal, Visual, and Delayed WMS-R Indices. Thus, it appears that the aspects of attention measured by these tests significantly contributed to memory performance. Such a finding highlights the importance of incorporating a range of attentional measures when carrying out an assessment of memory function following severe TBI.

Consistent with the literature, the results of the current study therefore found evidence of preserved immediate but compromised long-term memory function following severe TBI (e.g. Bennett-Levy, 1984; Brooks, 1975; 1976; Levin 1990; Levin & Goldstein, 1986). The results revealed that when the influence of attention on memory was controlled, differences between the two groups on the memory tasks were no longer apparent. This suggests that the memory deficits often reported in individuals who have sustained a severe TBI may not be memory deficits per se, but rather deficits in attention or speed of information processing that may be compromising otherwise intact memory function. The findings of the current study should alert rehabilitation clinicians to the importance of assessing attention in people who have suffered a TBI before making a diagnosis of memory impairment or recommending memory rehabilitation. It may well be that many of the strategies and programs used in the rehabilitation of memory disorders need to place more of a focus upon attentional training techniques.

CHAPTER 7

The Nature and Assessment of Attention Following Severe TBI: Summary, Recommendations and Conclusions

7.1 Background

The seven studies reported within this thesis investigated questions arising from the author's clinical practice involving individuals who had sustained a severe TBI. It was apparent from observations within a post-acute rehabilitation clinic that while patients, or their significant others, were reporting difficulties with attention in everyday life, limited emphasis was often placed upon the objective assessment and rehabilitation of attention. This was in direct contrast to the emphasis placed upon other cognitive functions, such as memory, where quite comprehensive assessment and rehabilitation protocols were administered. Furthermore, it was apparent that attentional problems may be contributing to deficits in these other cognitive functions. Also of note were reports of perceived improvement in attentional function several years post-injury. These observations prompted a number of questions which were investigated within this thesis.

A review of the literature revealed that although attentional deficits are frequently reported following TBI (Gronwall, 1987; McKinlay et al., 1981; van Zomeren & Brouwer, 1987), some studies have failed to find any objective evidence of deficits in attention (e.g. Brouwer & Wolffelaar, 1985; Stuss et al., 1985; van Zomeren et al., 1984). Where deficits in attention have been found, some authors have attributed these deficits to a reduced speed of information processing rather than specific attentional processes (e.g. Ponsford & Kinsella, 1992; Spikman et al., 1996; van Zomeren & Brouwer, 1997). Thus, there is a significant diversity of opinion within the literature regarding the attentional functioning of persons who have sustained a severe TBI. As a result, clinicians are often uncertain as to how to approach the measurement and rehabilitation of attention (Ponsford & Kinsella, 1992).

There are a number of factors that may contribute to these discrepant findings. In particular, a consensus of opinion regarding a model of attention and its underlying components has only recently emerged (Leon-Carrion et al., 1996). As a result, the development of specific measures of attention has lagged behind the development of measures of other cognitive functions (Mirsky et al., 1991). In addition, many of the measures currently used in the assessment of attention are highly multifactorial in nature, drawing upon a number of other cognitive processes in addition to attention (e.g. memory). Consequently, impaired performance on these tasks cannot be attributed to attentional processes alone. Moreover, many of these tasks have poor ecological validity (Kerns & Mateer, 1996) and do not correlate well with reports of attentional function in everyday life (Ponsford & Kinsella, 1991).

In order to examine the nature and extent of deficits in attention following severe TBI, it was necessary to identify:

(1) a model of attention upon which this study of attention could be based.

(2) a task or tasks that:

    (a) were based upon this model,

    (b) could assess attention independent of speed of information processing factors or other cognitive operations; and

    (c) had established ecological validity.

There was also a need to identify a standardized interview or questionnaire measure to assess the self and significant other reports of attentional function, and to then examine the relationship between these reports and objective measures of attention.

7.2 A Model of Attention

In recent years, a consensus has emerged in support of the model of attention proposed by Posner and colleagues (Posner & Petersen, 1990). This model consists of three parts including (1) an anterior system, which is responsible for selecting relevant stimuli and inhibiting irrelevant ones; (2) a posterior system, responsible for the visual orienting of attention; and (3) a vigilance system, responsible for maintaining a preparedness to respond in the absence of external cues. Moreover, the Posner model integrates a number of previously identified components of attention (i.e. focused attention, divided attention, sustained attention) and provides a theoretical basis for the assessment of attention. The structure and stability of this model has been verified using factor analyses of a range of psychometric measures, across a range of diagnostic groups (Leon-Carrion et al., 1996).

7.3 Choice of measures

A review of the literature revealed two tasks from within the experimental (the Covert Orienting of Attention Task - COAT) and clinical (the Test of Everyday Attention - TEA) literature that addressed the above criteria. Both of these tasks were based upon the model of attention devised by Posner (Posner & Petersen, 1990). In addition, a questionnaire measure of self and significant others perception of attentional function in everyday life was also identified (The Rating Scale of Attentional Behaviour).

According to Posner and Cohen (1982), the COAT is able to identify the most basic of all cognitive functions, namely the orienting of attention toward an event. As such, the COAT is a highly specific test of attention, with only minimal reliance upon other cognitive processes. A particular advantage of the COAT is that it enables the experimenter to examine the contribution of information processing speed to performance, via the manipulation of cue-target intervals. This feature is important given that attentional deficits following severe TBI may be the result of deficits in speed of information processing (e.g. Ponsford & Kinsella, 1992; Spikman et al., 1996).

The TEA, on the other hand, consists of a battery of tests and is based on the Posner model (Robertson et al., 1994). Unlike the COAT, it was developed specifically for use in clinical practice. A key feature of the TEA is that it has attempted to address the issue of ecological validity by incorporating tasks that resemble the types of tasks faced by people in everyday life. In addition, the TEA is one of the few tests to include a dual task when assessing attention. Robertson (1995) has suggested that dual tasks are sensitive to attentional deficits, particularly divided attention deficits. Surprisingly, however, few studies have examined the performance of severe TBI participants on the TEA. As the COAT and TEA are both based upon the Posner model of attention, they would appear to be ideal measures to assess attention following severe TBI.

Given the fact that the COAT and the TEA address some of the limitations of current clinical measures of attention, they were included as key tasks within this thesis. However, as these measures are not currently widely used within clinical practice, commonly used clinical measures were also used. Although the limitations of these measures are acknowledged, they were included to (a) determine whether the results of previous studies that used these measures could be replicated, and (b) examine the relationship between these measures and the TEA. An examination of the relationship between objective measures of attention and subjective reports of attentional function in everyday life, was also central to this thesis. As a result, the Rating Scale of Attentional Behaviour (Ponsford & Kinsella, 1991), a scale devised specifically for TBI sufferers in rehabilitation settings, was incorporated into this thesis.

7.4 Aims of the Thesis

A review of the literature highlighted a number of issues related to the assessment of attention following severe TBI. These issues resulted in the formulation of a series of specific aims that formed the basis of the seven studies reported within this thesis. These aims were to:

(1) determine whether the COAT was able to identify any specific deficits in attentional orienting following severe TBI and, in particular, whether attentional deficits were still evident once the effects of speed of information processing were accounted for.

(2) examine the impact of a dual task presentation upon both the COAT and a secondary (Language) task.

(3) determine whether the findings of Robertson et al. (1994; 1996) and Chan (2000), that people who have sustained a TBI show deficits on the TEA sub-tests, could be replicated.

(4) determine whether previous research indicating deficits amongst TBI sufferers on a range of standardised psychometric tests could be replicated.

(5) examine the relationship between subjective (i.e. Rating Scale of Attentional Behaviour) and objective (conventional measures and the TEA) assessments of attentional function.

(6) examine the recovery in attentional function.

(7) examine the relationship between attention and memory function.

(8) make recommendations regarding the assessment of attention following severe TBI.

7.5 The Design of the Thesis

This thesis was comprised of a series of seven studies. Studies 1 to 3 were based upon various adaptations of the COAT, while Study 4 examined differences between the TBI and Control groups on the TEA, as well as a series of conventional neuropsychological and self-report questionnaire measures. Recovery of attention over time was examined using both a cross-sectional (Study 5) and a longitudinal (Study 6) analysis. The final study (Study 7) sought to establish the relationship between memory and attention following severe TBI.

Only TBI participants with severe injuries (as determined by GCS and PTA scores) were included within the studies. A number of previous studies included both moderate and severe TBI participants within the same group, making the results more difficult to interpret (e.g. Chan, 2000). Efforts were also made to match participants from the TBI and Control groups in all of the studies with regard to age, sex, education, and premorbid IQ. The premorbid estimate was obtained from scores on the NART-R. While participants in Studies 1, 2 & 4 were matched for age and education, there was a significant difference between the two groups in premorbid IQ. As a result the data from Studies 1, 2 & 4 were originally analysed using the NART-R as a covariate (refer to Bate et al., 2001a; Bate et al., 2001b). However, because more recent concerns have been raised about the validity of the NART as an estimate of premorbid IQ, particularly in the first 12 months following severe TBI (e.g. Freeman et al., 2001; Riley & Simmonds, 2003), the NART-R was not used as a covariate in the current analyses. When comparing the results of the current analyses with the Bate et al., (2001a; 2001b) analyses, it was evident that the removal of the NART-R as a covariate had only a limited impact on the findings. For example, although the removal of the NART-R as a covariate resulted in statistically significant results being found on four additional sub-tests (i.e. PASAT 2.4 & 2.0 sec. rates, Elevator Counting with Reversal, and Lottery), the effect sizes of these sub-tests were only small to medium, suggesting that the clinical significance of these group differences was quite modest.

Unlike the COAT studies cited within the Chapter 3 literature review (e.g. Posner, 1980, Posner et al., 1982; Posner et al., 1984; Posner et al., 1987), the COAT studies within this thesis also controlled for the effects of finger tapping speed. Following TBI, there are often disruptions in both motor speed and co-ordination (Ponsford, 1995). A finger tapping test was used in order to control for the influence of motor speed upon RTs on the COAT. Thus, the results could be considered a more specific indicator of the orienting of attention than previous studies which have examined the orienting of attention following TBI (e.g. Cremona-Meteyard et al., 1992; Cremona-Meteyard & Geffen, 1994; Sandson et al., 1988).

7.6 Key Findings

The results revealed that, overall, TBI participants were able to orient their attention in much the same way as Controls. Importantly, the COAT was able to differentiate between the contribution of speed of information processing and specific attentional processes to attentional orienting. This was demonstrated on the COAT (vertical) task where, when given sufficient time to process the cues (i.e. the longer cue-target interval of 1000 ms), TBI participants oriented their attention in the same way as Controls. However, when the cue-target interval was reduced (i.e. 150 and 550 ms) and participants had less time to process the information, the TBI group oriented their attention less well than Controls (i.e. reduced Benefit and Validity effects). While this finding did not reach significance in the horizontal presentation of the COAT, there was a trend in this direction. Thus, by manipulating the cue-target intervals, the COAT (vertical presentation) was able to demonstrate that the deficit in performance displayed by TBI participants at the shorter cue-target intervals was not the result of a specific deficit in the orienting of attention but rather a reduced speed of information processing. This finding is consistent with the reports in the literature of intact attentional function but reduced speed of information processing following severe TBI (e.g. Ponsford & Kinsella, 1992; Spikman et al., 1996). It was also consistent with the Posner model and the known pathophysiology of TBI (i.e. principally frontal and temporal lobe damage, DAI, with less likelihood of parietal lobe damage) which would predict intact attentional orienting (subserved by the posterior attention system within the parietal lobes) following TBI.

Another key finding was that the introduction of a secondary (Language) task resulted in an impairment in the orienting of attention in the TBI group under COAT vertical conditions. The TBI group also displayed a significant deficit on the Language task under dual task conditions. This deficit was evident when the Language task was presented in conjunction with the COAT under both horizontal and vertical conditions. These findings are also consistent with the model of attention proposed by Posner, which would predict that the introduction of the divided attention task would place greater demands on the anterior attention system, a system which, because it is located within the frontal lobes, is typically compromised following TBI. Finally, Study 3 revealed that, contrary to predictions, TBI participants were able to use endogenous (controlled) attentional processes to inhibit exogenous (reflexive) orienting to inappropriate or irrelevant stimuli.

Although the COAT studies provided some important insights into the nature of attentional function following severe TBI, the COAT is not typically used within clinical practice. In contrast, the TEA was specifically designed for clinical use. Surprisingly though, few studies have been published on the TEA with severe TBI groups. Significant differences between the TBI and Control groups were found within Study 4 on the Map Search, Telephone Search, Visual Elevator, Elevator Counting with Reversal, and Lottery subtests, suggesting deficits in visual selective attention, sustained attention, and alternating attention following severe TBI.

Conventional neuropsychological measures were also included in this thesis to determine whether the results of previous studies could be replicated. The majority of these tests were able to detect differences between the groups (i.e. Stroop Colour Word and Modified Colour

Word, Symbol Digit Modalities Test – Written and Oral, Ruff 2's and 7's Selective Attention Test, and PASAT), thus replicating the findings of previous studies, and suggestive of deficits in selective, divided, and sustained attention following severe TBI. However, the mutltifactorial nature of these tasks made it unclear as to whether these differences were the result of attentional, speed of information processing, or other cognitive deficits. In addition, as revealed in previous studies within the literature, there were also poor correlations between these measures and self/significant other reports (e.g. Gronwall, 1991; Ponsford & Kinsella, 1991).

A principal components analysis of the TEA and conventional neuropsychological tests revealed a factor structure largely consistent with previous studies (e.g. Chan, 2000; Robertson, et al., 1994;1996). This factor structure included visual selective attention, attentional switching, sustained attention, and divided attention, and was also consistent with the components of attention identified in the Posner model (ie selective network, orienting network, vigilance network). The existence of this attentional structure provides a framework for a comprehensive assessment of attentional function.

Perhaps the most surprising finding within this thesis was evidence of recovery in attentional function beyond 2 years post-injury (Study 6). TBI participants who were more than 2 years post-injury showed a significant reduction in errors on the COAT Language task when they were re-tested after a 12 month period. This improvement was in excess of the changes shown by the Early TBI and Control groups and could not, therefore, be explained in terms of practice effects. Importantly, this improvement in divided attention was replicated under both horizontal and vertical COAT conditions. Further evidence of recovery beyond 24 months post-injury was also found in two visual selective attention tasks (Visual Elevator, Telephone Search). In contrast, there was some evidence of a decline in sustained attention.

The final study (Study 7) highlighted the close relationship between attention and memory. Although TBI participants performed at a significantly lower level than Controls on the WMS-R, when attention was statistically controlled for within the analysis, differences between the TBI and Control groups on the memory tasks were no longer evident. Thus, it would appear that the deficits in performance displayed by TBI participants on the WMS-R were the result of attentional deficits rather than memory deficits per se.

7.7 Recommendations for the Assessment of Attention following Severe TBI

Unfortunately, experimental and theoretical developments in the assessment of attention have been slow to filter through to clinical practice. However, Posner's model provides clinicians with a theoretical foundation upon which to base their assessment of attention following severe TBI. The four factor component structure (i.e. visual selective attention, attentional switching, divided attention, sustained attention) described by both Robertson et al. (1994; 1996) and Chan (2000) provides a framework for such an assessment. Moreover, the TEA contains sub-tests capable of assessing these components. It is suggested that the TEA, with its more ecologically valid measures, should form the core of an attentional assessment, with clinicians ensuring that they also include at least two measures from each of the four components outlined in Table 7.1. The use of other conventional neuropsychological tests to assess these attentional components should be done with caution. It is important that the clinician is aware that many of these measures, together with the TEA, contain multifactorial elements and, as a result, they must interpret their findings accordingly. For example it may be that in their report they conclude that their patient "*...has displayed an impairment on tasks sensitive to focussed attention function*", rather than declaring the patient "*...has a specific focussed attention deficit*".

TABLE 7.1 Recommended assessment measures for each of the components of attention.

Visual Selective Attention	**Attentional Switching**	**Divided Attention**	**Sustained Attention**
Stroop (Interference Effect)	Visual Elevator	Telephone Search while Counting (TEA)	Lottery (TEA)
Ruff 2s and 7s Selective Attention Test	Elevator Counting with Distraction	PASAT	Elevator Counting (TEA)
Map Search (TEA)		Trail Making Test	Continuous Performance Test
Telephone Search (TEA)			

The importance of including a dual task to assess divided attention has been highlighted throughout this thesis. Divided attention has been typically assessed by presenting the patient with a task that requires the manipulation of a number of operations within the same task (e.g. the PASAT). However, a dual task format may more closely represent the type of divided attention demands within everyday life. The ability of the dual (Language) task used within the COAT paradigm to detect improvements in performance over a 12 month period, highlights the sensitivity of this task to variations in attentional function. While this dual task is not generally available within clinical practice, the dual task within the TEA, although not revealing significant differences between TBI and Control participants in the current study, provides one alternative. Unfortunately it is one of the few, if not only, dual tasks available for use in clinical practice.

In addition to including psychometric measures within the clinical assessment of attention, there is also a need to incorporate an instrument that assesses everyday attention problems. It is suggested that the Rating Scale of Attentional Behaviour (Ponsford & Kinsella, 1991) is capable of providing such information.

As indicated, the assessment and rehabilitation of attentional function has not received the same emphasis as other cognitive functions (e.g. memory). However, the finding that there is a moderate relationship between attentional function and performance on the WMS-R, suggests that the contribution of attentional processes to an individual's memory function should be carefully examined, and that it may be attentional, rather than memory deficits, which should be the focus of rehabilitation efforts.

7.8 Limitations of Thesis

While this thesis has produced a number of key findings in relation to the nature and assessment of attentional function following severe TBI, some limitations are also evident. For example, despite acknowledging the multifactorial nature of many of the tasks used to assess attention, including the TEA, a number of the conclusions and recommendations in this thesis are still based upon these measures. This is particularly the case when recommending tasks to assess each of the components of attention. It is suggested that this reflects the practice within the literature of 'recruiting' existing tasks to 'fit' within the component structure, rather than developing new tasks that are based upon the conceptual underpinnings of these components. Thus, assessments based upon many of these measures should still be interpreted with some caution.

Another limitation of the current study was the failure to take into account the participants current mood state. While the entry criteria for the study excluded participants who had a history of psychiatric illness, there was no measure of mood state or any assessment for post-traumatic stress disorder (PTSD). It is possible that some of the attention deficits displayed by the TBI sufferers in the current study may have been as a result of depression or PTSD, rather than the neuropathology associated with TBI.

Although the sample sizes for the majority of the analyses within this thesis were relatively large ($N_{TBI} = 35$, $N_{Control} = 35$) compared to many other studies of TBI, the sample sizes used when comparing initial and re-test differences between the Early TBI (n = 9), Late TBI (n = 5), and Control (n = 12) groups on the Rating Scale of Attentional Behaviour were much smaller. In many ways the sample sizes within this thesis were imposed by both geographical and time constraints. The study was carried out in a regional city (population = approximately 1 million) which contained only one rehabilitation service. However, a larger sample size would have provided a more representative sample of this patient group.

Finally, this thesis included no measure of effort. While participants were informed that the data would not be used for medico-legal purposes, it is possible that some participants may have displayed reduced effort in order to achieve some secondary gain (e.g. in situations where compensation claims may have been pending).

7.9 Suggestions for Future Research

Clinicians and researchers have traditionally relied upon ‘pencil and paper’ tasks to assess attention and other cognitive functions. However, the findings of this thesis revealed the important contribution of computer-generated tasks in the assessment of attention. Computer-generated tasks have the potential to isolate specific attentional processes, thereby reducing the influence of deficits in speed of information processing or other cognitive functions. Thus, there is a need for future research to focus on the development of such tasks, along with norms, for use in clinical practice. However, it is important that these new computer generated tasks are built upon a model of attention and its component structure.

Tasks that are capable of accurately assessing attentional function have important applications to everyday life. In South Australia, there is a mandatory cancellation of the drivers license of a person who has sustained a severe TBI. It is suggested that reaction time tasks, such as the COAT, may well have a role to play in the assessment of attentional function in TBI sufferers when they apply for the reinstatement of their license. However, there will certainly need to be more research into developing normative data before tasks such as the COAT can be used to make such clinical and legal judgements and establish its relationship to driving.

The finding in this thesis that recovery may still be occurring beyond two years post-injury has significant implications for rehabilitation planners and policy makers. The delivery of rehabilitation, at least within Australia, has been strongly influenced by the view that most of the recovery of function occurs within the first 12 months post TBI, and tends to plateau before the end of the second year. As a result, most patients are discharged from the tertiary phase (i.e. community/outpatient rehabilitation) of their rehabilitation within the first 12 to 18 months of injury. It is therefore recommended that a more comprehensive study of the recovery of function be conducted. Such a study should include a larger cohort of participants and monitor changes in function over a longer period of time.

The studies within this thesis contained a number of measures that failed to find any differences between the TBI and Control groups. However, the lack of statistically significant findings may not be a reason for discarding these measures as clinically useful tools. The size of the standard deviations on a number of the tests suggests that certain participants may well have performed at deficit levels. This finding is consistent with the acknowledgement within the literature of significant heterogeneity within the TBI population (Coppens, 1995; Wilson, 1990). In addition, the preliminary data reported by Coppens (1995) suggests that there may be distinct subgroups within the TBI population (e.g. diffuse axonal injury group, focal & diffuse group). Thus, any future research projects will need to include significantly increased numbers in order to identify sub-groups within the TBI population and to analyse any differences between these groups (Felmingham, Baguley, & Green, 2004).

7.10 Summary and Conclusions

Attentional deficits are frequently reported following severe TBI. However, the literature is unclear about the exact nature of these deficits and the means by which they should be assessed. Thus, clinicians are often unsure about how to approach the assessment and rehabilitation of attention. Much of this uncertainty results from the fact that, until relatively recently, there was little consensus within the literature with regard to an accepted model of attention and its theoretical components. Many of the limitations associated with conventional measures of attention are a legacy of this previously inadequate theory and model development. Within recent years, however, there has been growing support for the model of attention developed by Posner. This model is now providing some coherence within the literature with regard to promoting an understanding of the theoretical underpinnings of attention and the components that should be assessed.

The Posner model was central in the development of the COAT and TEA, two of the key tasks used in the experimental studies within this thesis. The performance of severe TBI participants on the COAT revealed **intact orienting of attention** but a **reduced speed of information processing** compared to Controls. In addition, the reduced performance on both the COAT and Language task under dual task conditions confirmed a **divided attention deficit** following severe TBI. These COAT findings are particularly relevant to attentional function in everyday life. While TBI sufferers may be able to orient their attention sufficiently well to accurately and safely navigate their normal day-to-day environment, there may be situations, such as when driving a motor vehicle, in which the reduced time available to process the information, or the introduction of another demand upon attention, may result in impaired attentional performance.

The COAT therefore provides a means by which to isolate specific attentional orienting processes from other cognitive functions, such as speed of information processing and memory. It is suggested that such specificity is much easier to achieve using computer generated, as opposed to 'pencil and paper', testing formats. The impaired performance of TBI participants on the Language task, administered in conjunction with the COAT, has also highlighted the importance of including dual tasks in the assessment of divided attention.

The move toward developing more ecologically valid measures, such as the TEA, is a welcome addition to attentional assessment. All too often there has been a hiatus between subjective reports of attentional function in everyday life and clinical assessment findings. The findings of the current study revealed significant differences between the TBI and Control groups on a number of the TEA sub-tests and conventional neuropsychological measures, indicating **deficits in visual selective, divided, and sustained attention** following severe TBI. However, while the TEA is a much welcome addition to the assessment of attention, there is a danger that the move toward more ecologically valid tasks will result in tasks becoming even more multifactorial in nature. As a result it will be difficult to determine whether deficits on these tasks are the result of attentional or other cognitive processes. Clinicians will therefore need to strike a compromise between using tests that are ecologically valid and those that are based upon more specific experimental paradigms (e.g. RT tasks).

The findings of some **recovery of attentional function** in a group of TBI participants who were more than 2 years post injury challenges the commonly held view that little if any recovery occurs beyond this time. If this finding can be confirmed by future investigations, it will have significant implications for rehabilitation planning and policy development.

The challenge now for both researchers and clinicians is to focus on the development of theoretically-based tasks capable of identifying specific attentional processes and to ensure that these tasks can be readily used in clinical practice (i.e. by providing norms and a useable format).

REFERENCES

Adams, J. H., Graham, D. I., Scott, G., Parker, L. S., & Doyle, D. (1980). Brain damage in non-missile head injury. *Journal of Clinical Pathology, 33*, 1132-1145.

Adams, J. H., Doyle, D., & Graham, D. I. (1984). Diffuse axonal injuries in head injuries caused by a fall. *Lancet, ii*, 1420-1422.

Adams, J. H., Graham, D. I., & Gennarelli, T. A. (1985). Contemporary neuropathological considerations regarding brain damage in head injury. In D. P. Becker & J. T. Povlishock (Eds.), *Central nervous system trauma. Status report - 1985* . Washington, DC: National Institute of Health.

Adams, J. H., Doyle, D., Graham, D. I., Lawrence, A. E., & McLellan, D. R. (1986). Gliding contusions in nonmissile head injury in humans. *Archives of Pathology and Laboratory Medicine, 110*(6), 485-488.

Adams, J. H., Graham, D. I., Gennarelli, T. A., & Maxwell, W. L. (1991). Diffuse axonal injury in non-missile head injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 54*, 481-483.

Albensi, B., & Janigro, D. (2003). Traumatic brain injury and its effects on synaptic plasticity. *Brain Injury, 17*(8), 653-663.

Albert, M. L. (1973). A simple test of visual neglect. *Neurology, 23*, 658-665.

Allport, A. (1993). Attention and control: have we been asking the wrong questions? A critical review of twenty-five years. In Meyer & Kornblum (Eds.), *Attention and Performance* (Vol. *XIV*). Hillsdale, N.J: Lawrence Erlbaum. .

Alves, W. M., Colohan, A., O'Leary, T. J., Rimel, R. W., & Jane, J. A. (1986). Understanding post-traumatic symptoms after minor head injury. *Journal of Head Trauma Rehabilitation, 1*, 1-12.

Alves, W., Macciocchi, S. N., & Barth, J. T. (1993). Postconcussive symptoms after uncomplicated mild head injury. *Journal of Head Trauma Rehabilitation, 8*(3), 48 - 59.

Anderson, V. E., Siegal, F. S., Fisch, R. O., & Wirt, D. (1969). Response of phenylketonuric children on a continuous performance test. *Journal of Abnormal Psychology, 74*, 358 - 362.

Anderson, D. W., & McLaurin, R. L. (1980). Report on the National Head and Spinal Cord Injury Survey. *Journal of Neurosurgery, 53*(suppl.), S1-S43.

Anderson, S. I., Wilson, C. L., McDowell, I. P., Pentland, B., Gray, J. M., & Robertson, I. H. (1996). Late rehabilitation for closed head injury: a follow-up study of patients 1 year from time of discharge. *Brain Injury, 10*(2), 115-124.

Annegers, J. F., Grabow, H. D., Kurland, L. T., & Laws, E. R. (1980). The incidence, causes and secular trends in head injury in Olmsted County, Minnesota, 1935-1974. *Neurology, 30*, 912-919.

Asikainen, I., Kaste, M., & Sarna, S. (1998). Predicting late outcome for patients with traumatic brain injury referred to a rehabilitation programme: a study of 508 Finnish patients 5 years or more after injury. *Brain Injury, 12*(2), 95 - 107.

Atkinson, R. C., & Shiffren, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 2,). New York: Academic Press.

Bach-y-Rita, P. (1992). Recovery from brain damage. *Journal of Neurologic Rehabilitation, 6*(4), 191-199.

Bach-y-Rita, P. (2003). Theoretical basis for brain plasticity after TBI. *Brain Injury, 17*(8), 643-651.

Backman, L., & Dixon, R. A. (1992). Psychological compensation: a theoretical framework. *Psychological Bulletin, 112*(2), 259 - 283.

Badcock, K. A. (1987). *The head injury study at Flinders Medical Centre. A research report prepared for the South Australian Health Commission.* Adelaide: Department of Primary Health Care, Flinders Medical Centre.

Baddeley, A. D. (1966). The capacity for generating information by randomization. *Quarterly Journal of Experimental Psychology, 18*, 119-129.

Baddeley, A., Harris, J., Sunderland, A., Watts, K. P., & Wilson, B. A. (1987). Closed head injury and memory. In H. S. Levin, J. Grafman, & H. M. Eisenberg (Eds.), *Neurobehavioural Recovery From Head Injury* . New York: Oxford.

Baddeley, A. (1990). *Human memory: theory and practice*. London: Erlbaum.

Baddeley, A. (1993). Working memory or working attention? In A. Baddeley & L. Weiskrantz (Eds.), *Attention: Selection, Awareness, and Control* (pp. 152-170). Oxford: Clarendon Press.

Barth, J. T., Macciocchi, S. N., Boll, T. J., Giordani, B., Jane, J. A., & Rimel, R. W. (1983). Neuropsychological sequelae of minor head injury. *Neurosurgery, 13*, 529-533.

Barth, J. T., Alves, W. M., Ryan, T. V., Macciocchi, S. N., Rimel, R. W., Jane, J. J., & Nelson, W. E. (1989). Mild head injury in sports: Neuropsychological sequelae and recovery of function. In H. S. Levin, H. M. Eisenberg, & A. L. Benton (Eds.), *Mild Head Injury* (pp. 257 - 277). New York: Oxford University Press.

Bashinski, H. S., & Bacharach, V. R. (1980). Enhancement of perceptual sensitivity as the result of selectively attending to spatial locations. *Perceptual Psychophysiology, 28*, 241 - 248.

Batchelor, J., Harvey, A. G., & Bryant, R. A. (1995). Stroop Colour Word Test as a measure of attentional deficits following mild head injury. *The Clinical Neuropsychologist, 9*(2), 180 - 186.

Bate, A. J., Mathias, J. L., & Crawford, J. R. (2001a). The covert orienting of visual attention following severe traumatic brain injury. *Journal of Clinical and Experimental Neuropsychology, 23*(3), 386-398.

Bate, A. J., Mathias, J. L., & Crawford, J. R. (2001b). Performance on the Test of Everyday Attention and standard tests of attention following severe traumatic brain injury. *The Clinical Neuropsychologist, 15*(3), 405-422.

Ben-Yishay, Y., Piasetsky, E. B., & Rattock, J. (1987). A systematic method for ameliorating disorders in basic attention. In M. J. Meier, A. L. Benton, & L. Diller (Eds.), *Neuropsychological Rehabilitation* . New York: Churchill Livingstone.

Ben-Yishay, Y., Silver, S., Piasetsky, E., & Rattok, J. (1987). Relationship between employability and vocational outcome after intensive holistic cognitive rehabilitation. *Journal of Head Trauma Rehabilitation, 2*, 35 - 48.

Benavidez, D. A., Fletcher, J. M., Hannay, H. J., Bland, S. T., Caudle, E., Mendelsohn, D. B., Brunder, J., Harward, H., Song, J., Perachio, N.A., Bruce, D., Scheibel, R.S., Lilly, M.A., Verger-Maestre, K., & Levin, H.S. (1999). Corpus callosum damage and interhemispheric transfer of information following closed head injury in children. *Cortex, 35*, 315-336.

Bennett-Levy, J. (1984). Long-term effects of severe closed head injury on memory: Evidence from a consecutive series of young adults. *Acta Neurologica Scandinavica, 70*, 285 - 298.

Best, J. B. (1986). *Cognitive psychology*. St Paul: West Publishing Co.

Bigler, E. D., Kurth, S. M., Blatter, D., & Abildskov, T. (1992). Degenerative changes in traumatic brain injury: post-injury magnetic resonance identified ventricular expansion compared to pre-injury levels. *Brain Research Bulletin, 28*, 651-653.

Bigler, E. D. (1992). Three-dimensional image analysis of trauma-induced degenerative changes: An aid to neuropsychological assessment. *Archives of Clinical Neuropsychology, 7*, 449 - 456.

Bigler, E. D. (2000). Neuroimaging and outcome. In R. G. Frank & T. R. Elliot (Eds.), *Handbook of Rehabilitation Psychology* . Washington, DC: American Psychological Association.

Bigler, E. (2001 (a)). Quantative magnetic resonance imaging in traumatic brain injury. *Journal of Head Trauma Rehabilitation, 16*(2), 117-134.

Bigler, E. D. (2001 (b)). The lesion(s) in traumatic brain injury: implications for clinical neuropsychology. *Archives of Clinical Neuropsychology, 16*, 95-131.

Binder, L. (1986). Persisting symptoms after mild head injury: a review of the postconcussive syndrome. *Journal of Clinical and Experimental Neuropsychology, 8*, 323-346.

Binder, J., Marshall, R., Lazar, R., Benjamin, J., & Mohr, J. P. (1992). Distinct syndromes of hemineglect. *Archives of Neurology, 49*, 1187 - 1194.

Black, F. W. (1986). Digit repetition in brain-damaged adults: Clinical and theoretical implications. *Journal of Clinical Psychology, 42*, 770 - 782.

Blumbergs, P. C. (1997). Pathology. In P. R. R. Bullock (Ed.), *Head Injury* . London: Chapman & Hall.

Boake, C., Freelands, J. C., Ringholz, G. M., Nance, M. L., & Edwards, K. E. (1995). Awareness of memory loss after severe closed-head injury. *Brain Injury, 9*(3), 273-283.

Body, C., & Leathem, J. (1996). Incidence and aetiology of head injury in a New Zealand adolescent sample. *Brain Injury, 10*(8), 567-573.

Bohnen, N., Jolles, J., & Twijnstra, A. (1992). Modification of the Stroop Color Word Test improves differentiation between patients with mild head injury and matched controls. *The Clinical Neuropsychologist, 6*(2), 178-184.

Bond, M. R. (1975). Assessment of psychosocial outcome after severe head injury (pp. 141-157): CIBA Foundation.

Bond, M. R., & Brooks, D. N. (1976). Understanding the process of recovery as a basis for the investigation of rehabilitation for the brain injured. *Scandinavian Journal of Rehabilitation Medicine, 8*, 127-133.

Bond, M. (1984). The psychiatry of closed head injury. In N. Brooks (Ed.), *Closed Head Injury: Psychological, Social and Family Consequences* (pp. 148-178). London: Oxford University Press.

Bond, M. R. (1986). Neurobehavioural sequelae of closed head injury. In I. Grant & K. M. Adams (Eds.), *Neuropsychological assessment of neuropsychiatric disorders.* . New York: Oxford University Press.

Bornstein, R. A. (1986). Normative data on intermanual differences on three tests of motor performance. *Journal of Clinical and Experimental Neuropsychology, 8*, 12 - 20.

Bostrom, K., & Helander, C. G. (1986). Aspects on pathology and neuropathology in head injury. *Acta Neurochirurgica, (Suppl. 36)*, 51-55.

Bradshaw, J. L., Nettleton, N. C., Pierson, J. M., Wilson, L. E., & Nathan, G. (1987). Coordinates of extracorporeal space. In M. Jeannerod (Ed.), *Neurophysiological and neuropsychological aspects of spatial neglect* (pp. 41 - 67). Amsterdam: Elsevier.

Brickenkamp, R. (1981). *Test d2: Concentration Endurance Test: Manual.* Gottingen: Verlag.

Broadbent, D. E. (1958). *Perception and Communication.* London: Pergamon.

Broadbent, D. E. (1971). *Decision and Stress.* New York: Academic Press.

Brooks, D. N. (1974). Recognition memory and head injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 37*, 224-230.

Brooks, D. N. (1976). Recognition memory after head injury: a signal detection analysis. *Cortex, 10*, 224-230.

Brooks, D. N., Aughton, M. E., Bond, M. R., Jones, P., & Rizui, S. (1980). Cognitive sequelae in relationship to early indices of severity of brain damage after severe blunt head injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 43*, 529 - 534.

Brooks, D. N. (1983). Disorders of memory. In W. Rosenthal, R. Griffith, M. Bond, & J. D. Miller (Eds.), *Rehabilitation of the head-injured adult* (pp. 185 - 196). Philadelphia: Davis.

Brooks, N. (1984). *Closed head injury: psychological, social, and family consequences.* Oxford: Oxford University Press.

Brooks, N., Campsie, L., Symington, C., Beattie, A., & McKinlay, W. (1986). The five year outcome of severe blunt head injury: a relative's view. *Journal of Neurology, Neurosurgery, and Psychiatry, 49*, 764-770.

Brooks, N., McKinlay, W., Symington, C., Beattie, A., & Campsie, L. (1987). Return to work within the first seven years of severe head injury. *Brain Injury, 1*(1), 5-19.

Brooks, N. (1988). Personality change after severe head injury. *Acta Neurochirurgica, 44*(Suppl), 59-64.

Brooks, D. N. (1990). Cognitive deficits. In M. Rosenthal, E. R. Griffith, M. R. Bond, & J. D. Miller (Eds.), *Rehabilitation of the adult and child with traumatic brain injury* (2nd ed., pp. 165 - 178). Philadelphia: F.A. Davis.

Brouwer, W. H., & van Wolffelaar, P. C. (1985). Sustained attention and sustained effort after closed head injury: detection and 0.10 Hz heart rate variability in a low event rate vigilance task. *Cortex, 21*, 111-119.

Brown, J. (1958). Some tests of the decay theory of immediate memory. *Quarterly Journal of Experimental Psychology, 10*, 12 - 21.

Bullock, R., Zauner, A., Myseros, J.S., Marmarou, A., Woodward, J.J., & Young, H.F. (1995). Excitatory amino acid release patterns after severe head injury - experience with microdialysis in 30 patients. *Journal of Neurotrauma, 12(3)*, 372.

Chadwick, O., Rutter, M., Brown, G., Shaffer, D., & Traub, M. (1981). A prospective study of children with head injuries: II. Cognitive sequelae. *Psychological Medicine, 11*, 49 - 61.

Chan, R. C. K., Lee, T. M. C., & Hoosain, R. (1999). Application of the test of everyday attention in Hong Kong Chinese: A factor structure study. *Archives of Clinical Neuropsychology, 14*(8), 715-716.

Chan, R. C. K. (2000). Attentional deficits in patients with closed head injury: a further study to the discriminative validity of the test of everyday attention. *Brain Injury, 14*(3), 227-236.

Chan, R. C. K. (2001). Attentional deficits in patients with post-concussion symptoms: a componential perspective. *Brain Injury, 15*(1), 71-94.

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and with two ears. *The Journal of the Acoustical Society of America, 25*(5), 975-979.

Chong, B. W., Sanders, J. A., & Jones, G. A. (1999). Functional magnetic resonance imaging. In W. W. J. Orrison (Ed.), *Neuroimaging* . Philadelphia: W.B. Saunders & Co.

Cicerone, K. D. (1996). Attention deficits and dual task demands after mild traumatic brain injury. *Brain Injury, 10*(2), 79-89.

Clark, C. R., Geffen, G.M., & Geffen, L.B. (1989). Catecholamines and the covert orientation of attention in humans. *Neuropsychologia, 27*(2), 131-139.

Cohen, N. J., & Squire, L. R. (1980). Preserved learning and retention of pattern-analyzing skill in amnesia: Dissociation of knowing how and knowing that. *Science, 210*, 207 - 209.

Cohen, R. A., & O'Donnell, B. F. (1993). Disturbances of attention: neurological disease. In R. A. Cohen, Y. A. Sparling-Cohen, & B. F. O'Donnell (Eds.), *The Neuropsychology of Attention* . New York: Plenum Press.

Cooper, K. D., Tabaddor, K., Hauser, W. A., Shulman, K., Feiner, C., & Factor, P. R. (1983). The epidemiology of head injury in the Bronx. *Neuroepidemiology, 2*, 70-88.

Coppens, P. (1995). Subpopulations in closed-head injury: preliminary results. *Brain Injury, 9*(2), 195 - 208.

Corbetta, M., Miezin, F. M., Shulman, G. L., & Petersen, S. E. (1993). A PET study of visuospatial attention. *Journal of Neuroscience, 13*, 1202 - 1226.

Corrigan, J. D., & Mysiw, W. J. (1988). Agitation following traumatic brain injury: equivocal evidence for a discrete stage of cognitive recovery. *Archives of Physical Medicine and Rehabilitation, 69*, 487-492.

Corthell, D. W., & Tooman, M. (1985). *Rehabilitation of Traumatic Brain Injury. Twelfth Institute on Rehabilitation Issues*. Stout, Menominee, Wisconsin: Research and Training Center, University of Wisconsin.

Corwin, J., & Bylsma, F. W. (1993). Translations of excerpts from Andre Rey's *Psychological examination of traumatic encephalopathy* and P.A. Osterith's *The Complex Figure Copy Test. The Clinical Neuropsychologist, 7*, 3 - 15.

Costanzo, R. M., & Zasler, N. D. (1992). Epidemiology and pathophysiology of olfactory and gustatory dysfunction in head trauma. *Journal of Head Trauma Rehabilitation, 7*, 15-24.

Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information-processing system. *Psychological Bulletin, 104*(2), 163-191.

Crawford, J. R., Parker, D. M., & Besson, J. A. O. (1988). Estimation of premorbid intelligence in organic conditions. *British Journal of Psychiatry, 153*, 178-181.

Crawford, J. R. (1992). Current and premorbid intelligence measures in neuropsychological assessment. In J. R. Crawford, D. M. Parker, & W. W. McKinlay (Eds.), *A Handbook of Neuropsychological Assessment* . Hove: Lawrence Erlbaum.

Crawford, J. R., Sommerville, J., & Robertson, I. H. (1997). Assessing the reliability and abnormality of subtest differences on the test of everyday attention. *British Journal of Clinical Psychology, 36*, 609-617.

Cremona-Meteyard, S. L., Clark, C.R., Wright, M.J., & Geffen, G.M. (1992). Covert orientation of visual attention after closed head injury. *Neuropsychologia, 30*(2), 123-132.

Cremona-Meteyard, S. L., & Geffen, G.M. (1994). Persistent visuospatial attention deficits following mild head injury in australian rules football players. *Neuropsychologia, 32*(6), 649-662.

Crossen, J. R., & Wiens, A. N. (1988). Residual neuropsychological deficits following head-injury on the Wechsler Memory Scale-Revised. *Clinical Neuropsychologist, 2*(4), 393 - 399.

Crosson, B., Barco, P. P., Velozo, C. A., Bolesta, M. M., Cooper, P. V., Werts, D., & Brobeck, T. C. (1989). Awareness and compensation in postacute head injury rehabilitation. *Journal of Head Trauma Rehabilitation, 4*(3), 46-54.

Damasio, A. R. (1985). Prosopagnosia. *Trends in Neurosciences, 8*, 132 - 135.

Danckert, J., & Maruff, P. (1997). Manipulating the disengage operation of covert visual spatial attention. *Perception and Psychophysics, 59*(4), 500 - 508.

Danckert, J., Maruff, P., Crowe, S., & Currie, J. (1998). Inhibitory processes in covert orienting in patients with alzheimer's disease. *Neuropsychology, 12*(2), 225-241.

Davidoff, D. A., Laibstain, D. F., Kessler, H. R., & Mark, V. H. (1988). Neurobehavioural sequelae of minor head injury: a consideration of post-concussive syndromes versus post-traumatic stress disorder. *Cognitive Rehabilitation*, 8-13.

Denes, G., Semenza, C., Stoppa, E., & Lis, A. (1982). Unilateral spatial neglect and recovery from hemiplegia: A follow-up study. *Brain, 105*, 543 - 552.

Deutsch, J. A., & Deutsch, D. (1963). Attention: some theoretical considerations. *Psychological Review, 70*, 80-90.

Dikmen, S., Temkin, N., McLean, A., Wyler, A., & Machamer, J. (1987). Memory and head injury severity. *Journal of Neurology, Neurosurgery, and Psychiatry, 50*, 1613-1618.

Dikmen, S., Machamer, J., & Temkin, N. (1993). Psychosocial outcome in patients with moderate to severe head injury: Two year follow-up. *Brain Injury, 7*, 113 - 124.

Diller, L., Ben-Yishay, Y., Gerstman, L. J., Goodkin, R., Gordon, W., & Weinberg, J. (1974). Studies in cognition and rehabilitation in hemiplegia., *Rehabilitation Monograph No. 50* . New York: New York University Medical Center Institute of Rehabilitation Medicine.

Dimond, S. J. (1979). Performance by split-brain humans on lateralized vigilance tasks. *Cortex, 15*, 43 - 50.

Ericksen, C. W., & Hofman, J. E. (1972). Some characteristics of selective attention in visual perception determined by vocal reaction time. *Perceptual Psychophysiology, 11*, 169 - 171.

Eson, M. E., Yen, J. K., & Bourke, R. S. (1978). Assessment of recovery from serious head injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 41*, 1036 - 1042.

Evans, R. W. (1992). The post concussion syndrome and the sequelae of mild head injury. *Neurology Clinics, 10*, 815 - 847.

Ewert, J., Levin, H. S., Watson, M. G., & Kalisky, Z. (1989). Procedural memory during posttraumatic amnesia in survivors of severe closed head injury. *Archives of Neurology, 46*, 911 - 916.

Eysenck, M., & Keane, M. (1990). *Cognitive psychology: a student's handbook.* Hove: Lawrence Erlbaum.

Farmer, J., Gibler, M., Kavanaugh, R., & Johnson, J. (2000). Preventing traumatic brain injury: an innovative approach to outcome assessment. *Brain Injury, 14*(2), 109-115.

Felmingham, K. L., Baguley, I. J., & Green, A. M. (2004). Effects of diffuse axonal injury on speed of information processing following severe traumatic brain injury. *Neuropsychology, 18*(3), 564-571.

Fordyce, D. J., Roueche, J. R., & Prigatano, G. P. (1983). Enhanced emotional reactions in chronic head trauma patients. *Journal of Neurology, Neurosurgery, & Psychiatry, 46*, 620-624.

Forrester, G., Encel, J., & Geffen, G. (1994). Measuring post-traumatic amnesia (PTA): an historical perspective. *Brain Injury, 8*(2), 175-184.

Forrester, G., & Geffen, G. M. (1995). *Julia Farr Services Post-traumatic Amnesia Scales Manual.* Adelaide: Julia Farr Foundation.

Fortune, N., & Wen, X. (1999). *The definition, incidence and prevalence of acquired brain injury in Australia* . Canberra: Australian Institute of Health and Welfare.

Franzen, M. D., & Iverson, G. L. (2000). The Wechsler Memory Scales. In G. Groth-Marnat (Ed.), *Neuropsychological assessment in clinical practice: A guide to test interpretation and integration* (pp. 195 - 222). New York: John Wiley & Sons.

Freeman, J., Godfrey, H. P. D., Harris, J. K., & Partridge, F. M. (2001). Utility of a demographic equation in detecting impaired NART performance after TBI. *British Journal of Clinical Psychology, 40*, 221-224.

Friedrich, F. J., Egly, R., Rafal, R. D., & Beck, D. (1998). Spatial attention deficits in humans: a comparison of superior parietal and temporal-parietal junction lesions. *Neuropsychology, 12*(2), 193 - 207.

Frommer, G. F., & Smith, A. (1988). Kurt Goldstein and recovery of function, *Brain Injury and Recovery* . New York: Plenum Press.

Fryer, L. J., & Hafey, W. J. (1987). Cognitive rehabilitation and community readaptation: Outcomes from two program models. *Journal of Head Trauma Rehabilitation, 2*(3), 51 - 63.

Furst, C. (1986). The memory derby: evaluating and remediating intention memory. *Cognitive Rehabilitation*, 24-26.

Gaetz, M., & Bernstein, D. M. (2001). The current status of electrophysiological procedures for the assessment of mild traumatic brain injury. *Journal of Head Trauma Rehabilitation, 16*(4), 386-405.

Gainotti, G., D'Erme, P., Monteleone, D., & Silveri, M. C. (1986). Mechanisms of unilateral spatial neglect in relation to laterality of cerebral lesions. *Brain, 109*, 599 - 612.

Galbraith, S., Murray, W. R., Patel, A. R., & Knill-Jones, R. (1976). The relationship between alcohol and head injury, and its effects on the conscious level. *British Journal of Surgery, 63*, 128 - 130.

Gale, S. D., Johnson, S. J., Bigler, E. D., & Blatter, D. D. (1994). Traumatic brain injury and temporal horn enlargement: Correlates with tests of intelligence and memory. *Neuropsychiatry, Neuropsychology, and Behavioural Neurology, 7*, 160 - 165.

Gale, S., Hopkins, R., Weaver, L., Bigler, E., Booth, E., & Blatter, D. (1999). MRI, quantative MRI, SPECT, and neuropsychological findings following carbon monoxide poisoning. *Brain Injury, 13*(4), 229-243.

Gaultieri, T., & Cox, D. R. (1991). The delayed neurobehavioural sequelea of traumatic brain injury. *Brain Injury, 5*, 219 - 232.

Gawryszewski, L., Riggio, L., Rizzolatti, & Umilta, C. (1987). Movements of attention in the three spatial dimensions and the meaning of three 'neutral' cues. *Neuropsychologia, 25*, 19 - 29.

Geldmacher, D. S., & Hills, E. C. (1997). Effect of stimulus number, target-to-distractor ratio, and motor speed on visual spatial search quality following traumatic brain injury. *Brain Injury, 11*, 59 - 66.

Gennarelli, T. A., & Thibault, L. E. (1982). Biomechanics of acute subdural haematoma. *Journal of Head Trauma, 22*, 680-686.

Gennarelli, T. A., Thibault, L. E., Adams, J. H., Graham, D. I., Thompson, C. J., & Marcincin, R. P. (1982). Diffuse axonal Injury and traumatic coma in the primate. *Annals of Neurology, 12*, 564-574.

Gennarelli, T. A. (1986). Mechanisms and pathophysiology of cerebral concussion. *Journal of Head Trauma Rehabilitation, 1*, 23 - 29.

Gentry, L. R., Godersky, J. C., & Thompson, B. H. (1988). Trauma to the corpus callosum: MR features. *American Journal of Neuroradiology, 9*, 1129-1138.

Geschwind, N. (1982). Disorders of attention: a fronteir in neuropsychology. *Phil. Transcripts Royal Society of London, B 298*, 173-185.

Glisky, E., Schacter, D., & Tulving, E. (1986). Computer learning by memory impaired patients: acquisition and retention of complex knowledge. *Neuropsychologia, 24*, 313 - 328.

Godefroy, O., Lhullier, C., & Rousseaux, M. (1996). Non-spatial attention disorders in patients with frontal or posterior brain damage. *Brain, 119*, 191-202.

Godfrey, H. P. D., Partridge, E. M., & Knight, R. G. (1993). Course of insight disorder and emotional dysfunction following closed head injury: a controlled cross-sectional follow-up study. *Journal of Clinical and Experimental Neuropsychology, 15*, 503-515.

Golden, C. J. (1978). *Stroop Colour and Word Test.* Chicago: Stoelting.

Goldstein, F. C., & Levin, H. S. (1990). Epidemiology of traumatic brain injury: Incidence, clinical characteristics, and risk factors. In E. D. Bigler (Ed.), *Traumatic Brain Injury* . Austin, Texas: Pro-ed.

Goldstein, F. C., Levin, H. S., Goldman, W. P., Clark, A. N., & Altonen, T. K. (2001). Cognitive and neurobehavioural functioning after mild versus moderate traumatic brain injury in older adults. *Journal of the International Neuropsychological Society, 7*(3), 373 - 383.

Grafman, J., & Salazar, S. (1987). Methodological considerations relevant to the comparison of recovery from penetrating and closed head injuries. In H. S. Levin, J. Grafman, & H. M. Eisenberg (Eds.), *Neurobehavioural recovery from head injury.* New York: Oxford University Press.

Gray, S. (2000). Slow-to-recover severe traumatic brain injury: a review of outcomes and rehabilitation effectiveness. *Brain Injury, 11*, 1003-1014.

Greenwood, R. (1997). Value of recording duration of post-traumatic amnesia. *Lancet, 349,* 1041 - 1042.

Groher, M. E. (1990). Speech and language assessment. In M. Rosenthal, E.R. Griffith, M. Bond, & J.D. Miller (Eds.), *Rehabilitation of the adult and child with traumatic brain injury* (pp. 294 - 309). Philadelphia: F.A. Davis.

Gronwall, D. M. A., & Sampson, H. (1974). *The psychological effects of concussion.* Auckland: Auckland University Press.

Gronwall, D., & Wrightson, P. (1974). Delayed recovery of intellectual function after minor head injury. *Lancet, 2*, 605 - 609.

Gronwall, D. M. A. (1977). Paced auditory serial addition task: a measure of recovery from concussion. *Perceptual and Motor Skills, 44*, 367-373.

Gronwall, D., & Wrightson, P. (1981). Memory and information processing capacity after closed head injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 44*, 889-895.

Gronwall, D. (1987). Advances in the assessment of attention and information processing after head injury. In H.S. Levin, J. Grafman, & H.M. Eisenberg (Eds.), *Neurobehavioural Recovery from Head Injury* (pp. 354-371). New York: Oxford University Press.

Gronwall, D. (1989). Cumulative and persisting effects of concussion on attention and cognition. In H. S. Levin, H. M. Eisenberg, & A. L. Benton (Eds.), *Mild head injury* . New York: Oxford University Press.

Gronwall, D. (1991). Minor head injury. *Neuropsychology, 5*, 253-265.

Grossman, R. I., & Yousem, D. M. (1994). *Neuroradiology: The Requisites*. St Louis: Mosby.

Groswasser, Z., Reider-Groswasser, I., Soroker, N., & Machtey, Y. (1987). Magnetic resonance imaging in head injured patients with normal late computed tomography scans. *Surgical Neurology, 27*, 331 - 337.

Grubb, R. L., & Coxe, W. S. (1978). Trauma to the central nervous system. In S. G. Eliasson, A. L. Prensky, & W. B. Hardin (Eds.), *Neurological pathophysiology* . New York: Oxford University Press.

Guha, A. (2004). Management of traumatic brain injury: some current evidence and applications. *Postgraduate Medical Journal, 80*, 650 - 653.

Haddon, W., Valien, P., McCarroll, J. R., & Umberger, C. J. (1962). A controlled investigation of the characteristics of adult pedestrians fatally injured by motor vehicles in Manhattan. *Journal of Chronic Diseases, 14*, 655 - 661.

Halliday, A. (1999). Pathophysiology. In D. W. Marion (Ed.), *Traumatic Brain Injury* . New York: Thieme.

Halligan, P. W., Cockburn, J., & Wilson, B. A. (1991). The behavioural assessment of visual neglect. *Neuropsychological Rehabilitation, 1*, 5 - 32.

Halligan, P. W., & Robertson, I. H. (1992). The assessment of unilateral neglect. In J. R. Crawford, D. M. Parker, & e. al (Eds.), *A handbook of neuropsychological assessment* (pp. 151 - 175). Hillsdale, NJ: Lawrence Erlbaum.

Hannay, H. J., Levin, H. S., & Grossman, R. G. (1979). Impaired recognition memory after head injury. *Cortex, 15*, 269.

Hart, T., & Hayden, M. E. (1986). The ecological validity of neuropsychological assessment and remediation. In B. P. Uzzell & Y. Gross (Eds.), *Clinical Neuropsychology of Intervention* (pp. 21-50). Boston: Martinus Nijhoff Publishing.

Hartman, A., Pickering, R. M., & Wilson, B. A. (1992). Is there a central executive deficit after severe head injury? *Clinical Rehabilitation, 6*, 133-140.

Hayes, R. L. (1996). Neurochemical changes in traumatic brain injury. In H. S. Levin, A. L. Benton, J. P. Muizelaar, & H. M. Eisenberg (Eds.), *Catastrophic Brain Injury* . New York: Oxford University Press.

Hebb, D. O. (1947). The effects of early experience on problem solving at maturity. *American Psychologist, 2*, 306 - 307.

Hecaen, H., & Albert, M. (1978). *Human Neuropsychology*. New York: John Wiley and Sons.

Heilman, K. M., Safran, A., & Geschwind, M. (1971). Closed head trauma and aphasia. *Journal of Neurology, Neurosurgery, and Psychiatry, 34*, 265.

Heilman, K. M., Watson, R. T., Valenstein, E., & Damasio, A. R. (1983). Localization of lesions in neglect. In A. Kertesz (Ed.), *Localization in neuropsychology* . New York: Academic Press.

Hendryx, P. M. (1989). Psychosocial changes perceived by closed-head injured adults and their families. *Archives of Physical Medicine and Rehabilitation, 70*, 526-530.

Hickling, E. J., Gillen, R., Blanchard, E. B., Buckley, T., & Taylor, A. (1998). Traumatic brain injury and posttraumatic stress disorder: a preliminary investigation of neuropsychological test results in PTSD secondary to motor vehicle accidents. *Brain Injury, 12*(4), 265-274.

Hillier, S. L., Hiller, J. E., & Metzer, J. (1997). Epidemiology of traumatic brain injury in South Australia. *Brain Injury, 11*(9), 649-659.

Hillier, S. L., Sharpe, M. H., & Metzer, J. (1997). Outcomes 5 years post-traumatic brain injury (with further reference to neurophysical impairment and disability). *Brain Injury, 11*, 661 - 675.

Hiorns, O., & Newcombe, F. (1979). Recovery curves: uses and limitations. *International Rehabilitation Medicine, 1*, 173 - 176.

Hoschwender, W. J. (1988). The mechanics of a knockout punch. *Popular Mechanics, 77*, 112 - 113.

Humphrey, M., & Oddy, M. (1980). Return to work after head injury: a review of post-war studies. *Injury, 12*, 107 - 114.

Ingraham, L. J., Bridge, T. P., Janssen, R., Stover, E., & Mirsky, A. F. (1990). Neuropsychological effects of early HIV-1 infection: Assessment and methodology. *The Journal of Neuropsychiatry and Clinical Neurosciences, 2*, 174 - 182.

Ishihara, S. (1972). *Tests for Colour Blindness*. Tokyo: Kanehara Shuppan.

Jacobs, H. E. (1987). The Los Angeles head injury survey: project rationale and design implications. *Journal of Head Trauma Rehabilitation, 2*, 37-50.

Jacobs, H. E. (1990). Identifying post-traumatic behaviour problems: Data from psychosocial follow-up studies. In R. L. Wood (Ed.), *Neurobehavioural sequelae of traumatic brain injury* . Philadelphia: Taylor & Francis.

Jagger, J., Levine, J. I., Jane, J. A., & Rimel, R. W. (1984). Epidemiological features of head injury in a predominantly rural population. *Journal of Trauma, 24*, 40-44.

James, W. (1950; reprint of original edition published by Henry Holt & Co. 1890). *The Principles of Psychology*. (Vol. 1). New York.

Jenkins, A., Teasdale, G., Hadley, M. D. M., Macpherson, P., & Rowan, J. O. (1986). Brain lesions detected by magnetic resonance imaging in mild and severe head injuries. *Lancet, 2*, 445-446.

Jennet, W. B. (1975). *Epilepsy after Non-Missile Head Injuries*. Chicago: Mosby Year Book.

Jennett, B., & Teasdale, G. (1981). *Management of head injuries.* Philadelphia: FA Davis.

Jennett, B., & Macmillan, R. (1981). Epidemiology of head injury. *British Medical Journal, 282*, 101-104.

Jennett, B. (1996). Epidemiology of head injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 60*, 362-369.

Johansson, E., Ronnkvist, M., & Fugl-Meyer, A. R. (1991). Traumatic brain injury in northern Sweden. *Scandinavian Journal of Rehabilitation Medicine, 23*, 179-185.

Johnston, W. W., & Heinz, S. P. (1978). Flexibility and capacity demands of attention. *Journal of Experimental Psychology: General, 107*, 420 - 435.

Johnston, W. A., & Dark, V. J. (1986). Selective attention. *Annual Review of Psychology, 37*, 43-75.

Johnstone, B., Erdal, K., & Stadler, M. A. (1995). The relationship between the Wechsler Memory Scale - Revised (WMS-R) Attention Index and putative measures of attention. *Journal of Clinical Psychology in Medical Settings, 2*(2), 195 - 204.

Jones, N. R., Blumbergs, P. C., Brown, C. J., McLean, A. J., Manavis, J., Perrett, L. V., Sandhu, A., Scott, G., & Simpson, D. A. (1998). Correlation of postmortem MRI and CT appearances with neuropathology in brain trauma: a comparison of two methods. *Journal of Clinical Neuroscience, 5*(1), 73 - 79.

Jonides. (1981). Voluntary versus automatic control over the mind's eye's movement. In J. B. Long & A. D. Baddeley (Eds.), *Attention and Performance* (Vol. IX). Hillsdale, NJ: Lawrence Erlbaum.

Jonides, J., & Mack, R. (1984). On the cost and benefit of cost and benefit. *Psychological Bulletin, 96*(1), 29-44.

Kahneman, D. (1973). *Attention and Effort.* Engelwood Cliffs, NJ: Prentice-Hall.

Kahneman, D., & Triesman, A. (1984). Changing views of attention and automaticity. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of Attention.* London: Academic Press.

Kalsbeek, W. D., McLaurin, R. L., Harris, B. S. H., & Miller, J. D. (1980). The national head and spinal cord injury survey: major findings. *Journal of Neurosurgery, 53 (suppl.)*, S19 - S30.

Kaplan, S. P. (1993). Five-year tracking of psychosocial changes in people with severe traumatic brain injury. *Rehabilitation Counselling Bulletin, 36*(3), 151-159.

Katz, D.I. & Mills, V.M. (1999). Traumatic brain injury: Natural history and efficacy of cognitive rehabilitation. In D.T. Stuss, G. Wincour, & I.H. Robertson (Eds.), *Cognitive rehabilitation* (pp. 279-301). London UK: Cambridge University Press.

Katz, D. I. (1992). Neuropathology and neurobehavioural recovery from closed head injury. *Journal of Head Trauma Rehabilitation, 7*(2), 1-15.

Kay, T., Cavallo, M. M., Ezrachi, O., & Vavagiakis, P. (1995). The Head Injury Family Interview: A clinical and research tool. *Journal of Head Trauma Rehabilitation, 10*(2), 12 - 31.

Kerns, K. A., & Mateer, C. A. (1996). Walking and chewing gum: The impact of attentional capacity on everyday activities. In R. J. Sbordone & C. J. Long (Eds.), *Ecological validity of neuropsychological testing* (pp. 147-169). Delray Beech, Florida: GR Press/St Lucie Press.

Kersel, D. A., Marsh, N. V., Havill, J. H., & Sleigh, J. W. (2001). Neuropsychological functioning during the year following severe traumatic brain injury. *Brain Injury, 15*(4), 283 - 296.

Kesler, S. R., Adams, H. F., & Bigler, E. (2000). SPECT, MR and quantitative MR imaging: correlates with neuropsychological and psychological outcome in traumatic brain injury. *Brain Injury, 14*(10), 851-857.

Killiany, R. J., Moss, M. B., Albert, M. S., Sandor, T., Tieman, J., & Jolesz, F. (1993). Temporal lobe regions on magnetic resonance imaging identify patients with early Alzheimer's disease. *Archives of Neurology, 50*(9), 949 - 954.

Kimonides, S. (1995). *An investigation into the relationship between prospective memory and executive functions in adults following traumatic brain injury.* Melbourne: La Trobe University.

Kinsella, G., Moran, C., Ford, B., & Ponsford, J. (1988). Emotional disorder and its assessment within the severe head injured population. *Psychological Medicine, 18*, 57-63.

Kinsella, G., Murtagh, D., Landry, A., Homfray, K., Hammond, M., O'Bierne, L., Dwyer, D., Lamong, M., & Ponsford, J. (1996). Everyday memory following traumatic brain injury. *Brain Injury, 10*, 499 - 507.

Kinsella, G. J., & Ong, B. (1997). Slips in performance of delayed intentions. *Australian Journal of Psychology, 49*, 139.

Kinsella, G. J. (1998). Assessment of attention following traumatic brain injury: a review. *Neuropsychological Rehabilitation, 8*(3), 351-375.

Klein, F. C. (24 November 1982). Silent epidemic: head injuries difficult to diagnose, get rising attention. *Wall Street Journal*, 1 - 12.

Klonoff, H., Low, M. D., & Clark, C. (1977). Head injuries in children: a prospective five year follow-up. *Journal of Neurology, Neurosurgery, and Psychiatry, 40*, 1211-1219.

Kolb, B., & Whishaw, I. Q. (1985). *Fundamentals of human neuropsychology.* (2nd ed.). New York: Freeman.

Kolb, B. (1995). *Brain Plasticity and Behaviour*. Mahwah, NJ: Lawrence Erlbaum.

Kraus, J. F. (1987). Epidemiology of head injury. In P. R. Cooper (Ed.), *Head Injury* (2nd ed.). Baltimore: Williams and Wilkins.

Kreutzer, J. S., Wehman, P., Morton, M. V., & Stonnington, H. H. (1988). Supported employment and compensatory strategies for enhancing vocational outcome following traumatic brain injury. *Brain Injury, 2*(3), 205 - 223.

Kucera, H. F., W. N. (1967). *Computational Analysis of Present-Day American English.* Providence, Rhode Island: Brown University Press.

Kurtzke, J. F. (1984). Neuroepidemiology. *Annals of Neurology, 16*, 265 - 277.

Kwentus, J. A., Hart, R. P., Peck, E. T., & Kornstein, S. (1985). Psychiatric complications of closed head trauma. *Psychosomatics, 26*, 8 - 17.

Ladavas, E. (1987). Is the hemispatial deficit produced by right parietal lobe damage associated with retinal or gravitational coordinates. *Brain, 110*, 167 - 180.

Lam, C. S., Priddy, D. A., & Johnson, P. (1991). Neuropsychological indicators of employability following traumatic brain injury. *Rehabilitation Counselling Bulletin, 35*, 68-74.

Langfitt, T. W., Obrist, W. D., Alavi, A., Grossman, R. I., Zimmerman, R., Jaggi, J., Uzzell, J., Uzzell, B., Reivich, M., & Patton, D. R. (1986). Computerized tomography, magnetic resonance imaging and positron emission tomography in the study of brain trauma. Preliminary observations. *Journal of Neurosurgery, 64*, 760 - 767.

Langfitt, T. W., Obrist, W. D., Alavi, A., Grossman, R., Zimmerman, R., Jaggi, J., Uzzell, B., Reivich, M., & Patton, D. (1987). Regional structure and function in head injured patients: correlation of CT, MRI, PET, CBF and neuropsychological assessment. In H. S. Levin, J. Grafman, & H. M. Eisenberg (Eds.), *Neurobehavioural Recovery from Head Injury* (pp. 30-42). New York: Oxford University Press.

Larsson, C., & Ronnberg, J. (1987). Memory disorders as a function of traumatic brain injury. Word completion, recall of words and actions. *Scandinavian Journal of Rehabilitaion Medicine, 19*(3), 99 - 104.

Leon-Carrion, J., Rodriguez-Duarte, R., Barroso-Martin, J. M., Machuca, F., & Dominguez-Morales, M. R. (1996). The attention system in brain injury survivors. *International Journal of Neuroscience, 85*, 231-236.

Levander, M. B., & Sonesson, B. G. (1998). Are there any mild interhemisphere effects after moderately severe closed head injury? *Brain Injury, 12*, 165-173.

Levin, H. S., Grossman, R. G., & Kelly, P. J. (1976). Aphasic disorder in patients with closed head injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 39*, 1062 - 1070.

Levin, H. S., & Grossman, R. G. (1978). Behavioural sequelae of closed head injury: a quantitative study. *Archives of Neurology, 35*, 720-727.

Levin, H. S., O'Donnell, V. M., & Grossman, R. G. (1979). The Galveston Orientation and Amnesia Test. *Journal of Nervous and Mental Diseases, 167*, 675-684.

Levin, H. S., & Eisenberg, H. M. (1979). Neuropsychological outcome of closed head injury in children and adolescents. *Child's Brain, 5*, 282 - 292.

Levin, H. S., Grossman, R. G., Rose, J. E., & Teasdale, G. (1979). Long-term neuropsychological outcome of closed head injury. *Journal of Neurosurgery, 50*, 412-422.

Levin, H. S., Myers, C. A., Grossman, R. G., & Sarwar, M. (1981). Ventricular enlargement after closed head injury. *Archives of Neurology, 38*, 623 - 629.

Levin, H. S., Benton, A. L., & Grossman, R. G. (1982). *Neurobehavioural consequences of closed head injury.* New York: Oxford University Press.

Levin, H. S., & Benton, A. L. (1984). Neuropsychologic assessment. In A. B. Baker & L. B. Baker (Eds.), *Clinical Neurology* (pp. 1-21). Philadelphia: Harper & Rowe.

Levin, H. S., & Goldstein, F. C. (1986). Organisation of verbal memory after severe closed-head injury. *Journal of Clinical and Experimental Neuropsychology, 8*, 643 - 656.

Levin, H. S., Amparo, E., Eisenberg, H. M., Williams, D. H., High, W. M., Jr., McArdle, C. B., & Weiner, R. L. (1987). Magnetic resonance imaging and computerised tomography in relation to the neurobehavioural sequelae of mild and moderate head injuries. *Journal of Neurosurgery, 66*, 706-713.

Levin, H. S., Mattis, S., Ruff, R. M., Eisenberg, H. M., Marshall, L. F., Tabaddor, K., High, W. M., & Frankowski, R. F. (1987). Neurobehavioural outcome following minor head injury: a three-center study. *Journal of Neurosurgery, 66*, 234-243.

Levin, H. S. (1990). Memory deficits after closed head injury. *Journal of Clinical and Experimental Neuropsychology, 12*(1), 129-153.

Levin, H. S., Goldstein, F. C., Williams, D. H., & Eisenberg, H. M. (1991). The contribution of frontal lobe lesions to the neurobehavioural outcome of closed head injury. In H. S. Levin, H. M. Eisenberg, & A. L. Benton (Eds.), *Frontal lobe function and dysfunction* . New York: Oxford University Press.

Levy, M. L., Davis, S., & Russell, M. (1999). Penetrating brain injuries: Ballistics and forensic. In D. W. Marion (Ed.), *Traumatic brain injury* (pp. 201 - 213). New York: Thieme Medical Publishers, Inc.

Lewine, J. D., Davis, J. T., Sloan, J. H., Kodituwakku, P., & Orrison, W. W. (1999). Neuromagnetic assessment of pathophysiological brain activity induced by minor head trauma. *American Journal of Neuroradiology, 20*, 857-866.

Lezak. (1978). Living with the characterologically altered brain injured patient. *Journal of Clinical Psychiatry, 39*, 592 - 598.

Lezak, M. D. (1979). Recovery of memory and learning functions following traumatic brain injury. *Cortex, 15*, 63-70.

Lezak, M. (1982). The problem of assessing executive functions. *International Journal of Psychology, 17*, 281 - 297.

Lezak, M. D. (1983). *Neuropsychological Assessment.* (2nd ed.). New York: Oxford University Press.

Lezak, M. D. (1995). *Neuropsychological Assessment.* (3nd ed:). New York: Oxford University Press.

Lindsay, P. H., & Norman, D. A. (1969). Short-term retention during a simultaneous detection task. *Perception and Psychophysics, 5*(4), 201 - 205.

Lindsay, P. H. (1970). Multichannel processing in perception. In D. I. Mostofsky (Ed.), *Attention: Contemporary theory and analysis.* New York: Appleton-Century-Crofts.

Lishman, W. A. (1973). The psychiatric sequelae of head injuries: a review. *Psychological Medicine, 3*, 304-317.

Lishman, W. A. (1978). *Organic Psychiatry: The Psychological Consequences of Cerebral Disorder*. London: Blackwell.

Livingston, M. G., Brooks, D. N., & Bond, M. R. (1985). Patient outcomes in the year following severe head injury, and relatives' psychiatric and social functioning. *Journal of Neurology, Neurosurgery, and Psychiatry, 48*, 870-875.

Livingston, M. G., & Livingston, H. M. (1985). The Glasgow Assessment Schedule: clinical and research assessment of head injury outcome. *International Rehabilitation Medicine, 7*, 145 - 149.

Loken, W. J., Thornton, A. E., Otto, R. L., & Long, C. J. (1995). Sustained attention after severe closed head injury. *Neuropsychology, 9*(4), 592-598.

Lowe, D. G., & Mitterer, J. O. (1982). Selective and divided attention in a Stroop task. *Canadian Journal of Psychology, 36*, 684-700.

Luria, A. R. (1963). *Restoration of function after brain injury.* Oxford: Pergamon.

Luria, A. R. (1966). *Higher cortical functions in man.* New York: Basic Books.

Luria, A. R., Naydin, V. L., Tsvetkova, L. S., & Vinarskaya, E. N. (1975). Restoration of higher cortical functions following local brain damage. In P. J. Vinken & G. W. Bruyn (Eds.), *Handbook of clinical neurology* (pp. 368 - 433). New York: Elsevier.

Lye, T. C., & Shores, E. A. (2000). Traumatic brain injury as a risk factor for Alzheimer's disease: A review. *Neuropsychology Review, 10*(2), 115 - 129.

Mackie, R. R. (1977). *Vigilance, theory, operational performance and physiological correlates.* New York: Plenum Press.

Mandleberg, I. A. (1976). Cognitive recovery after severe head injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 39*, 1001 - 1007.

Mangels, J., Craik, F., Levine, B., Schwartz, M., & Stuss, D. (2000). Chronic deficits in item and context memory following traumatic brain injury: a function of attention and injury severity. *Brain and Cognition, 44*, 113-115.

Mapou, R. L. (1992). Neuropathology and neuropsychology of behavioural disturbances following traumatic brain injury. In C. J. Long & L. K. Ross (Eds.), *Handbook of Head Trauma - Early recovery care to recovery* (pp. 75-89). New York: Plenum Press.

Martzke, J. S., Swan, C. S., & Varney, N. R. (1991). Posttraumatic anosmia and orbital frontal damage: neuropsychological and neuropsychiatric correlates. *Neuropsychology, 5*, 213-225.

Maruff, P., & Currie, J. (1995). An attentional grasp reflex in patients with alzheimer's disease. *Neuropsychologia, 33*(6), 689 - 710.

Maruff, P., Pantelis, C., Danckert, J., Smith, D., & Currie, J. (1996). Deficits in the endogenous redirection of covert visual attention in chronis schizophrenia. *Neuropsychologia, 34*(11), 1079 - 1084.

Maruff, P., Yucel, M., Danckert, J., Stuart, G., & Currie, J. (1999). Facilitation and inhibition arising from the exogenous orienting of covert attention depends on the temporal properties of spatial cues and targets. *Neuropsychologia, 37*, 731 - 744.

Mateer, C. A., Sohlberg, M. M., & Crinean, J. (1987). Focus on clinical research: perceptions of memory function in individuals with closed head injury. *Journal of Head Trauma Rehabilitation, 2*(3), 74-84.

Mattson, A. J., & Levin, H. S. (1990). Frontal lobe dysfunction following closed head injury: a review of the literature. *The Journal of Nervous and Mental Disease, 178*(5), 282-291.

Mayeux, R., Ottman, R., & Tang, M. X. (1993). Genetic susceptibility and head injury as risk factors for Alzheimers disease among community-dwelling elderly persons and their first-degree relatives. *Annals of Neurology, 33*, 494-501.

McAllister, T. W., Saykin, A. J., Flashman, L. A., Sparling, M. B., Johnson, S. C., Guerin, S. J., Mamourian, A. C., Weaver, J. B., & Yanofsky, N. (1999). Brain activation during working memory 1 month after mild traumatic brain injury: a functional MRI study. *Neurology, 53*, 1300-1308.

McDowell, S., Whyte, J., & D'Esposito, M. (1997). Working memory impairments in traumatic brain injury: evidence from a dual task paradigm. *Neuropsychologia, 35*(10), 1341-1353.

McKinlay, W. W., Brooks, D. N., Bond, M. R., Martinage, D. P., & Marshall, M. M. (1981). The short term outcome of severe blunt head injury as reported by relatives of the injured persons. *Journal of Neurology, Neurosurgery, and Psychiatry, 44*, 527-533.

McLean, A., Dikmen, S., & Temkin, N. (1993). Psychosocial recovery after head injury. *Archives of Physical Medicine Rehabilitation, 74*, 1041-1046.

McMillan, T. M., & Glucksman, E. E. (1987). The neuropsychology of moderate head injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 50*, 393-397.

McMillan, T. M., & Herbert, C. M. (2004). Further recovery in a potential treatment withdrawal case 10 years after brain injury. *Brain Injury, 18*(9), 935-940.

McMordie, W. R., Barker, S. L., & Paolo, T. M. (1990). Return to work (RTW) after head injury. *Brain Injury, 4*, 57-69.

Meador, K. J., Loring, D. W., Bowers, D., & Heilman, K. M. (1987). Remote memory and neglect syndrome. *Neurology, 37*, 522 - 526.

Meier, M. J., Strauman, S., & Thompson, W. G. (1987). Individual differences in neuropsychological recovery: an overview. In M. J. Meier, A. L. Benton, & L. Diller (Eds.), *Neuropsychological Rehabilitation* (pp. 71-110). Edinburgh: Churchill Livingstone.

Merritt, H. (1959). *Textbook of Neurology.* (2nd ed.). Philadelphia: Lea and Febiger.

Miller, L. (1990). Major syndromes of aggressive behaviour following head injury: an introduction to evaluation and treatment. *Cognitive Rehabilitation, 8*(6), 14-19.

Miller, J. D., & Jones, P. A. (1990). Minor head injury. In M. Rosenthal, M. R. Bond, G. E.R., & J. D. Miller (Eds.), *Rehabilitation of the adult and child with traumatic brain injury* (2nd ed.,). Philadelphia: F.A. Davis.

Miller, L. (1996). Neuropsychology and pathophysiology of mild head injury and the postconcussion syndrome: clinical and forensic considerations. *The Journal of Cognitive Rehabilitation, January/February*, 8-23.

Mirsky, A. F., Primac, D. W., Ajmone Marson, C., Rosvold, H. E., & Stevens, J. A. (1960). A comparison of the psychological test performance of patients with focal and nonfocal epilepsy. *Experimental Neurology, 2*, 75-79.

Mirsky, A. F., & Duncan, C. C. (1986). Etiology and expression of schizophrenia: neurobiological and psychosocial factors. *Annual Review of Psychology, 37*, 291-319.

Mirsky, A. F. (1989). The neuropsychology of attention: elements of a complex behaviour. In E. Pereceman (Ed.), *Integrating Theory and Practice in Clinical Neuropsychology* (pp. 75-91). Hiilsdale, NJ: Erlbaum.

Mirsky, A. F., Anthony, B. J., Duncan, C. C., Ahearn, M. B., & Kellam, S. G. (1991). Analysis of the elements of attention: a neuropsychological approach. *Neuropsychology Review, 2*(2), 109-145.

Mishkin, M., & Petri, H. L. (1984). Memories and habits: some implications for the analysis of learning and retention. In L. R. Squire & N. Butter (Eds.), *Neuropsychology of Memory* . New York: Guilford Press.

Mitchell, D. B. (1989). How many memory systems? evidence from aging. *Journal of Experimental Psychology, 15*(1), 31-49.

Mittl, R. L., Grossman, R. I., Hiehle, J. F., Hurst, R. W., Kauder, D. R., Gennarelli, T. A., & Alburger, G. W. (1994). Prevalence of MR evidence of diffuse axonal injury in patients with mild head injury and normal head CT findings. *American Journal of Neuroradiology, 15*(8), 1583-1589.

Moore, A. D., & Stambrook, M. (1995). Cognitive moderators of outcome following traumatic brain injury: a conceptual model and implications for rehabilitation. *Brain Injury, 9*, 109-130.

Moray, N. (1959). Attention in dichotic listening: affective cues and the influence of instructions. *Quarterly Journal of Experimental Psychology, 11*, 56-60.

Murdoch, G. E. (1990). *Acquired speech and language disorders: A neuroanatomical and functional neurological approach.* New York: Chapman and Hall.

Murdoch, B. E. (1996). Physiological rehabilitation of disordered speech following closed head injury. In B. P. Uzzell & H. H. Stonnington (Eds.), *Recovery after traumatic brain injury* . Mahwah, New Jersey: Lawrence Erlbaum.

Naatanen, R. (1982). Processing negativity: An evoked potential reflection of selective attention. *Psychological Bulletin, 92*, 605 - 640.

Naatanen, R. (1992). *Attention and brain function.* Hillsdale, N.J.: Lawrence Erlbaum.

Najenson, T., Mendelson, L., Schechter, I., David, C., Mintz, N., & Groswasser, Z. (1974). Rehabilitation after severe head injury. *Scandinavian Journal of Rehabilitation Medicine, 6*, 5-14.

Najenson, T., Sazbon, L., Fiselzon, J., Becker, E., & Schecter, I. (1978). Recovery of communicative functions after prolonged traumatic coma. *Scandinavian Journal of Rehabilitation Medicine, 10*, 15-21.

Nelson, H. E. (1982). *National Adult Reading Test (NART): Test Manual.* Windsor: NFER-Nelson.

Nestvold, K., Lundar, T., Blikra, G., & Lonnum, A. (1988). Head injuries during one year in a central hospital in Norway: a prospective study. *Neuroepidemiology, 7*, 134-144.

Newcombe, F. (1982). The psychological consequences of closed head injury: assessment and rehabilitation. *Injury, 14*, 111-136.

Ninio, A., & Kahneman, D. (1974). Reaction time in focussed and in divided attention. *Journal of Experimental Psychology, 103(3)*, 394-399.

Nissen, M. (1986). Neuropsychology of attention and memory. *Journal of Head Trauma Rehabilitation, 1*(3), 13-21.

Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology, 19*, 1 - 32.

Norman, D. A. (1968). Toward a theory of memory and attention. *Psychological Review, 75*, 522 - 536.

Novack, T., Alderson, A. L., Bush, B., Meythaler, & Canupp. (2000). Cognitive and functional recovery at 6 and 12 months post TBI. *Brain Injury, 14*, 987 - 996.

Nudo, R. J., & Milliken, G. W. (1996). Reorganisation of movement representations in primary motor cortex following focal ischemic infarcts in adult squirrel monkeys. *Journal of Neurophysiology, 75*(5), 2144 - 2149.

O'Donnell, B. F., & Cohen, R. A. (1993). Attention: a component of information processing. In R.A. Cohen, Y.A. Sperling-Cohen, & B.F. O'Donnell (Eds.), *The neuropsychology of attention* (pp. 11-48). New York: Plenum.

O'Shaughnessy, E. J., Fowler, R. S., & Reid, V. (1984). Sequelae of mild closed head injuries. *Journal of Family Practice, 18*, 391-394.

Oddy, M., Humphrey, M., & Uttley, D. (1978). Subjective impairment and social recovery after closed head injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 41*, 611-616.

Oddy, M., Coughlan, T., Tyreman, A., & Jenkins, D. (1985). Social adjustment after closed head injury: A further follow-up seven years after injury. *Journal of Neurology, Neurosurgery and Psychiatry, 48*, 564 - 568.

Olver, J. H. (1995). Brain injury: the need to assess outcome. *Current Opinion in Neurology, 8*, 443 - 446.

Ommaya, A. K., Grubb, R. L., & Naumann. (1971). Coup and contre-coup injury: observations on the mechanics of visible brain injuries in the rhesus monkey. *Journal of Neurosurgery, 35*, 503-516.

Oppenheimer, D. R. (1968). Microscopic lesions in the brain following head injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 31*, 299-306.

Oppermann, J. D. (2004). Interpreting the meaning individuals ascribe to returning to work after traumatic brain injury: a qualitative approach. *Brain Injury, 18*(9), 941-955.

Ownsworth, T. L., & Oei, T. P. S. (1998). Depression after traumatic brain injury: conceptualization and treatment considerations. *Brain Injury, 12*(9), 735-751.

Pachet, A., Friesen, S., Winkelaar, D., & Gray, S. (2003). Beneficial behavioural effects of lamotrigine in traumatic brain injury. *Brain Injury, 17*(8), 715-722.

Page, S., & Levine, P. (2003). Forced use after TBI: promoting plasticity and function through practice. *Brain Injury, 17*(8), 675-684.

Page, S. J., & Yablon, S. (2003). Foreword. *Brain Injury, 17*(8), 639-641.

Parasuraman, R., & Haxby, J. V. (1993). Attention and brain function in Alzheimer's disease: a review. *Neuropsychology, 7*(3), 242-272.

Parasuraman, R., & Martin, A. (1994). Cognition in Alzheimer's disease: disorders of attention and semantic knowledge. *Current Opinions in Neurobiology, 4*, 237-244.

Parasurman, R., & Davies, D. R. (1984). *Varieties of Attention.* Orlando, FL: Academic Press.

Pardo, J. V., Fox, P. T., & Raichle, M. E. (1991). Localization of a human system for sustained attention by positron emission tomography. *Nature, 349*, 61-63.

Park, N. W., Moscovitch, M., & Robertson, I. H. (1999). Divided attention impairments after traumatic brain injury. *Neuropsychologia, 37*, 1119-1133.

Parker, S. A., & Serrats, A. F. (1976). Memory recovery after traumatic coma. *Acta Neurochirurgica, 34*, 71 - 77.

Parker, R. S. (1990). *Traumatic brain injury and neuropsychological impairment: Sensorimotor, cognitive, emotional, and adaptive problems of children and adults.* New York: Springer-Verlag.

Pavese, A., Heidrich, A., Sohlberg, M. M., Laughlin, K. A., & Posner, M. I. (1998). *Pathologies of attentional networks following traumatic brain injury* (Technical Report 97403): Institute of Cognitive and Decisions Sciences, University of Oregon Eugene.

Pavlov, I. (1927). *Conditioned reflexes.* Oxford: Clarendon Press.

Petersen, S. E., Robinson, D. L., & Morris, D. J. (1987). Contributions of the pulvinar to visual spatial attention. *Neuropsychologia, 25*, 97 - 195.

Petersen, S. E., Fox, P. T., Mintun, M. & Raichle, M.E. (1988). Positron emission tomographic studies of the cortical anatomy of single word processing. *Nature, 331*, 585-589.

Pfeffer, R. I., Kurosaki, T. T., Harrah, C. H., Chance, J. M., Bates, D., Detels, R., Filos, S., & Butzke, C. (1981). A survey diagnostic tool for senile dementia. *American Journal of Epidemiology, 114*, 515 - 527.

Ponsford, J. L. (1988). Neuropsychological assessment: the need for a more pragmatic approach. *Australian Psychologist, 23*(3), 349 - 360.

Ponsford, J., & Kinsella, G. (1991). The use of a rating scale of attentional behaviour. *Neuropsychological Rehabilitation, 1*(4), 241-257.

Ponsford, J., & Kinsella, G. (1992). Attentional deficits following closed head injury. *Journal of Clinical and Experimental Neuropsychology, 14*(5), 822-838.

Ponsford, J. (1995). Mechanisms, recovery, and sequelae of traumatic brain injury: a foundation for the REAL approach. In J. Ponsford, S. Sloan, & P. Snow (Eds.), *Traumatic Brain Injury: Rehabilitation for Everyday Adaptive Living* (pp. 1-31). Hove: Lawrence Erlbaum.

Ponsford, J. L., Olver, J. H., & Curran, C. (1995). A profile of outcome 2 years after traumatic brain injury. *Brain Injury, 9*(1), 1-10.

Ponsford, J. L., Olver, J. H., Curran, C., & Ng, K. (1995). Prediction of employment status 2 years after traumatic brain injury. *Brain Injury, 9*(1), 11 - 20.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information Processing and Cognition: The Loyola Symposium.* (pp. 55-85). Hillsdale, NJ: Erlbaum.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3-25.

Posner, M. I., Cohen, Y., & Rafal, R. D. (1982). Neural systems control of spatial orienting. *Phil. Trans. R. Soc. Lond., B 298*, 187-198.

Posner, M. I., Walker, J. A., Friedrich, F. J., & Rafal, R. D. (1984). Effects of parietal injury on covert orienting of attention. *The Journal of Neuroscience, 4*(7), 1863-1874.

Posner, M. I., Inhoff, A. W., Friedrich, F. J., & Cohen, A. (1987). Isolating attentional systems: a cognitive-anatomical approach analysis. *Psychobiology, 15*(2), 107-121.

Posner, M. I., & Rafal, R. D. (1987). Cognitive theories of attention and the rehabilitation of attentional deficits. In M. J. Meier, A. L. Benton, & L. Diller (Eds.), *Neuropsychological Rehabilitation* (pp. 182-201). New York: Churchill Livingstone.

Posner, M. I., Petersen, S. E., Fox, P. T. & Raichle, M. E. (1988). Localization of cognitive operations in the human brain. *Science, 240*, 1627-1631.

Posner, M. I., Sandson, J., Dhawan, M., & Shulman, G. L. (1989). Is word recognition automatic? A cognitive-anatomical approach. *Journal of Cognitive Neuroscience, 1*, 50 - 60.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*, 25-42.

Posner, M. I., & Raichle, M. E. (1994). *Images of Mind.* New York: Scientific American Library.

Povlishock, J. T., & Christman, C. W. (1995). The pathobiology of traumatically induced axonal injury in animals and humans: a review of current thoughts. *Journal of Neurotrauma, 12*, 555-564.

Prigatano, G. P. (1987). Neuropsychological deficits, personality variables, and outcome. In M. Ylvisaker & E. M. R. Gobble (Eds.), *Community reentry for head injured adults.* Boston: Little, Brown & Co.

Prigatano, G. P., & Altman, I. M. (1990). Impaired awareness of behavioural limitations after traumatic brain injury. *Archives of Physical Medicine and Rehabilitation, 71*, 1058-1064.

Prigatano, G. P. (1991). Disordered mind, wounded soul: the emerging role of psychotherapy in rehabilitation after brain injury. *Journal of Head Trauma Rehabilitation, 6*(4), 1-10.

Prigatano, G. P., & Schacter, D. L. (1991). *Awareness of Deficit after Brain Injury: Clinical and Theoretical issues.* New York: Oxford University Press.

Prigatano, G. P. (1992). Personality disturbances associated with traumatic brain injury. *Journal of Consulting and Clinical Psychology, 60*(3), 360-368.

Purves, D., & Voyvodic, J. T. (1987). Imaging mammalian nerve cells and their connections over time in living animals. *Trends in Neurosciences, 10*, 398 - 404.

Rafal, R. D., & Henik, A. (1994). The neurology of inhibition. Integrating controlled and automatic processes. In D. L. Dagenbach & V. Carr (Eds.), *Inhibitory processes in attention, memory and language* (pp. 1 - 50). New York: Academic Press.

Raskin, S. A., & Sohlberg, M. M. (1996). The efficacy of prospective memory training in two adults with brain injury. *Journal of Head Trauma Rehabilitation, 11*(3), 32 - 51.

Rasmusson, D. X., Brandt, J., Martin, D. B., & Folstein, M. F. (1995). Head injury as a risk factor in Alzheimer's disease. *Brain Injury, 9*(3), 213-219.

Reid, D. B., & Kelly, M. P. (1993). Wechsler Memory Scale-Revised in closed head injury. *Journal of Clinical Psychology, 49*(2), 245 - 254.

Reider-Grosswasser, I. I., Grosswasser, Z., Ommaya, A. K., Schwab, K., Pridgen, A., Brown, H. R., Cole, R., & Salazar, A. M. (2002). Quantative imaging in late traumatic brain injury. Part I: Late imaging parameters in closed and penetrating head injuries. *Brain Injury, 16*(6), 517 - 526.

Reitan, R. M. (1958). Validity of the Trail Making Test as an indicator of organic brain damage. *Perceptual and Motor Skills, 8*, 271 - 276.

Reitan, R. M., & Wolfson, D. (1993). *The Halstead-Reitan Neuropsychological Test Battery: Theory and clinical interpretation*. Tucson, Arizona: Neuropsychology Press.

Riccio, C. A., Reynolds, C. R., Lowe, P., & Moore, J. J. (2002). The continuous performance test: a window on the neural substrates for attention? *Archives of Clinical Neuropsychology, 17*, 235 - 272.

Richards, P. M., & Ruff, R. M. (1989). Motivational effects on neuropsychological functioning: comparison of depressed versus nondepressed individuals. *Journal of Consulting and Clinical Psychology, 57*, 396-402.

Richardson, J. (1990). *Clinical and neuropsychological aspects of closed head injury.* London: Taylor & Francis.

Ricker, J. H., Hillary, F. G., & DeLuca, J. (2001). Functionally activated brain imaging (0-15 PET and fMRI) in the study of learning and memory after traumatic brain injury. *Journal of Head Trauma Rehabilitation, 16*(2), 191-205.

Riley, G. A., & Simmonds, L. V. (2003). How robust is performance on the National Adult Reading Test following traumatic brain injury. *British Journal of Clinical Psychology, 42*, 319 - 328.

Rimel, R. W., Giordani, B., & Barth, J. T. (1982). Moderate head injury: completing the clinical spectrum of brain trauma. *Neurosurgery, 11*, 344-351.

Rimel, R. W., & Jane, J. A. (1984). Patient characteristics. In M. Rosenthal, E. R. Griffith, M. R. Bond, & J. D. Miller (Eds.), *Rehabilitation of the Head Injured Adult* (pp. 9-20). Philadelphia: Davis.

Rizzolatti, G., Riggio, L., Dascola, I., & Umilta, C. (1987). Reorienting attention across the horizontal and vertical meridians: evidence in favour of a premotor theory of attention. *Neuropsychologia, 25*, 31 - 40.

Robertson, I. H., Ward, T., Ridgeway, V., & Nimmo-Smith, I. (1994). *The Test of Everyday Attention*. Bury St. Edmunds: Thames Valley Test Company.

Robertson, I. H. (1995). *Neuropsychological Rehabilitation, Attention and Unilateral Neglect.* Paper presented at the International Neuropsychological Society / Australian Society for the Study of Brain Impairment annual conference. Cairns, Australia.

Robertson, I. H., Ward, T., Ridgeway, V., & Nimmo-Smith, I. (1996). The structure of normal human attention: the test of everyday attention. *Journal of the International Neuropsychological Society, 2*, 525-534.

Robertson, I. H., & Murre, J. M. J. (1999). Rehabilitation of brain damage: Brain plasticity and principles of guided recovery. *Psychological Bulletin, 125*(5), 544 - 575.

Rodin, E. (1967). Contributions of EEG to prognosis after head injury. *Diseases of the Nervous System, 28*, 598-601.

Roland, P. E. (1985). Cortical organisation of voluntary behaviour in man. *Human Neurobiology, 4*, 155-167.

Rosenthal, M., Griffith, E. R., Bond, M. R., & Miller, J. D. (1990). *Rehabilitation of the adult and child with traumatic brain injury.* (2nd ed.). Philadelphia: F.A. Davis.

Rosvold, H. E., Mirsky, A. F., Sarason, I., Bransome, E. D., & Beck, L. H. (1956). A continuous performance test of brain damage. *Journal of Consulting Psychology, 20*, 343 - 350.

Rowley, G., & Fielding, K. (1991). Reliability and accuracy of the Glasgow Coma Scale with experienced and inexperienced users. *The Lancet, 337*, 535-538.

Ruff, R. M., Evans, R. W., & Light, R. H. (1986). Automatic detection vs controlled search: a paper and pencil approach. *Perceptual and Motor Skills, 62*, 407-416.

Ruff, R. M., Niemann, H., Allen, C. C., Farrow, C. E., & Wylie, T. (1992). The Ruff 2 and 7 Selective Attention Test: A neuropsychological application. *Perceptual and Motor Skills, 75*, 1311 - 1319.

Ruff, R. M., Marshall, L. F., Crouch, J. A., Klauber, M. R., Levin, H. S., Barth, J. T., Kreutzer, J., Eisenberg, H. M., Jane, J. A., Marmarou, A., & Foulkes, M. A. (1993). Predictors of outcome following severe head trauma: Follow-up data from the Traumatic Coma Data Bank. *Brain Injury, 7*(2), 101 - 111.

Rugg, M. D., Milner, A. D., Lines, C. R., & Phalp, R. (1987). Modulation of visual event-related potentials by spatial and non-spatial visual selective attention. *Neuropsychologia, 25*, 85 - 96.

Russell, W. R., & Nathan, P. W. (1946). Traumatic amnesia. *Brain, 69*, 280-300.

Ryan, T. V., Sautter, S. W., Capps, C. F., Meneese, & Barth, J. T. (1992). Utilizing neuropsychological measures to predict vocational outcome in a head trauma population. *Brain Injury, 6*(2), 175 - 182.

Salazar, A. M., Grafman, J. H., Vance, S. C., Weingartner, H., Dillon, J.D., & Ludlow, C. (1986). Consciousness and amnesia after penetrating head injury: neurology and anatomy. *Neurology, 36*, 178-187.

Salmon, D. P., & Butters, N. (1987). Recent developments in learning and memory: implications for the rehabilitation of the amnesic patient. In M. J. Meier, A. L. Benton, & L. Diller (Eds.), *Neuropsychological Rehabilitation* . Edinburgh: Churchill Livingstone.

Sandson, J., Crosson, B., Posner, M. I., Barco, P. P., Velozo, C. A., & Brobeck, T. C. (1988). Attentional imbalances following head injury. In J. M. Williams & C. J. Long (Ed.), *Cognitive Approaches to Neuropsychology* . New York: Plenum.

Sbordone, R. J. (1984). Rehabilitative neuropsychological approach for severe traumatic brain injured patients. *Professional Psychology: Research and Practice, 15*(2), 165 - 175.

Sbordone, R. J. (1987). A conceptual model of neuropsychologically-based cognitive rehabilitation. In J.M. Williams & C.J. Long (Eds.), *The rehabilitation of cognitive disabilities* (pp. 3-27). New York: Plenum.

Sbordone, R. J., Liter, J. C., & Pettler-Jennings, P. (1995). Recovery of function following severe traumatic brain injury: a retrospective 10 year follow up. *Brain Injury, 9*(3), 285-299.

Sbordone, R. J. (1998). Ecological validity: some critical issues for the neuropsychologist. In R. J. Sbordone & C. J. Long (Eds.), *Ecological Validity of Neuropsychological Testing* (pp. 15-41). Boston: St Lucie Press.

Schacter, D. L., & Crovitz, H. F. (1977). Memory function after closed head injury: A review of the quantitive research. *Cortex, 13*, 150 - 176.

Schacter, D. L. (1987). Implicit memory: history and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 501-518.

Scherzer, B. P., Charbonneau, S., Solomon, C. R., & Lepore, F. (1993). Abstract thinking following severe traumatic brain injury. *Brain Injury, 7*(5), 411-423.

Schmitter-Edgecombe, M. (1996). Effects of traumatic brain injury on cognitive performance: an attentional resource hypothesis in search of data. *Journal of Head Trauma Rehabilitation, 11*(2), 17-30.

Schmitter-Edgecombe, M. (1996). Effects of divided attention on implicit and explicit memory performance following severe closed head injury. *Neuropsychology, 10*(2), 155-167.

Schmitter-Edgecombe, M., & Kibby, M. K. (1998). Visual selective attention after severe closed head injury. *Journal of the International Neuropsychological Society, 4*, 144-159.

Schmitter-Edgecombe, M., & Wright, M. J. (2004). Event-based prospective memory following severe closed-head injury. *Neuropsychology, 18*(2), 353-361.

Schofield, P. W., Tang, M., Marder, K., Bell, K., Dooneief, G., Chun, M., Sano, M., Stern, Y., & Mayeux, R. (1997). Alzheimer's disease after remote head injury: An incidence study. *Journal of Neurology, Neurosurgery, and Psychiatry, 62*, 119 - 124.

Schouten, J. W., Fulp, C. T., Royo, N. C., Saatman, K. E., Watson, D. J., Snyder, E. Y., Trojanowski, J. Q., Prockop, D. J., Maas, A. I. R., & McIntosh, T. K. (2004). A review and rationale for the use of cellular transplantation as a therapeutic strategy for traumatic brain injury. *Journal of Neurotrauma, 21*(11), 1501 - 1538.

Selecki, B. R., Ring, I. T., Simpson, D. A., Vanderfield, G. K., & Sewell, M. F. (1981). *Injuries to the head, spine and peripheral nerves: report on a study.* Canberra: Australian Government Printing Service.

Seniow, J., Polanowska, K., Mandat, T., & Laudanski, K. (2003). The cognitive impairements due to the occipito-parietal brain injury after gunshot. A successful neurorehabilitation case study. *Brain Injury, 17*(8), 701-713.

Shallice. (1982). Specific impairments of planning. *Philosophical Transactions of the Royal Society London, B, 298*, 199-209.

Shallice, T. (1988). *From Neuropsychology to Mental Structure.*: Cambridge University Press.

Shallice, T., & Burgess, P. (1991). Higher-order cognitive impairments and frontal lobe lesions in man. In H. S. Levin, H. M. Eisenberg, & A. L. Benton (Eds.), *Frontal lobe function and dysfunction* . New York: Oxford University Press.

Shallice, T., & Burgess, P. (1993). Supervisory control of action and thought selection. In A. Baddeley & L. Weiskrantz (Eds.), *Attention: Selection, Awareness, and Control* . Oxford: Clarendon Press.

Sherman, E. M. S., Strauss, E., & Spellacy, F. (1997). Validity of the Paced Auditory Serial Addition Test (PASAT) in adults refereed for neuropsychological assessment after head injury. *The Clinical Neuropsychologist, 11*(1), 34-45.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84*(2), 127-190.

Shimamura, A. P., Janowsky, J. S., & Squire, L. R. (1991). What is the role of frontal lobe damage in memory disorders? In H. S. Levin, H. M. Eisenberg, & A. L. Benton (Eds.), *Frontal lobe function and dysfunction* . New York: Oxford University Press.

Shores, E. A., Marosszeky, J. E., Sandanam, J., & Batchelor, J. (1986). Preliminary validation of a clinical scale for measuring duration of post traumatic amnesia. *Medical Journal of Australia, 144*, 569-572.

Shum, D. H. K., McFarland, K. A., & Bain, J. D. (1990). Construct validity of eight tests of attention: comparison of normal and closed head injured samples. *The Clinical Neuropsychologist, 4*(2), 151-162.

Shum, D. H. K., McFarland, K., & Bain, J. D. (1994). Assessment of attention: Relationship between psychological testing and information processing approaches. *Journal of Clinical and Experimental Neuropsychology, 16*, 531-538.

Shum, D., Sweeper, S., & Murray, R. (1996). Performance on verbal implicit and explicit memory tasks following traumatic brain injury. *Journal of Head Trauma Rehabilitation, 11*(2), 43 - 53.

Shum, D., Valentine, M., & Cutmore, T. (1999). Performance of individuals with severe long-term traumatic brain injury on time-, event-, and activity-based prospective memory tasks. *Journal of Clinical and Experimental Neuropsychology, 21*, 49-58.

Shum, D. H. K., Harris, D., & O'Gorman, J. G. (2000). Effects of severe traumatic brain injury on visual memory. *Journal of Clinical and Experimental Neuropsychology, 22*(1), 25-39.

Simpson, A., & Schmitter-Edgecombe, M. (2000). Intactness of inhibitory attentional mechanisms following severe closed-head injury. *Neuropsychology, 14*(2), 310-319.

Sivak, M., Olson, P.L., Kewman, D.G., Won, H. & Henson, D.L. (1981). Driving and perceptual/cognitive skills: Behavioural consequences of brain damage. *Archives of Physical Medicine Rehabilitation, 62*, 476.

Sloan, S., & Ponsford, J. (1995). Assessment of cognitive difficulties following TBI. In J. Ponsford, S. Sloan, & P. Snow (Eds.), *Traumatic Brain Injury: Rehabilitation for Everyday Adaptive Living* (pp. 65-102). Hove: Lawrence Erlbaum Associates.

Smith, A. (1973). *Symbol Digit Modalities Test.* Los Angeles: Western Psychological Services.

Smith, A. (1982). *Symbol Digit Modalities Test.* Los Angeles: Western Psychological Services.

Snoek, J., Jennett, B., Adams, J. H., Graham, D. I., & Doyle, D. (1979). Computerized tomography after recent severe head injury in patients without acute intrcranial hematoma. *Journal of Neurology, Neurosurgery, & Psychiatry., 42*, 215-225.

Snow, R. B., Zimmerman, R. D., Gandy, S. E., & Deck, M. D. F. (1986). Comparison of magnetic resonance imaging and computed tomography in the evaluation of head injury. *Neurosurgery, 18*, 45-52.

Sohlberg, M. M., & Mateer, C. A. (1989). *Introduction to Cognitive Rehabilitation: Theory and Practice.* New York: Guilford Press.

Sosin, D. M., Sniezek, J. E., & Thurman, D. J. (1996). Incidence of mild and moderate brain injury in the United States, 1991. *Brain Injury, 10*, 47-54.

Spikman, J. M., Berg, I. J., & Deelman, B. G. (1995). Spared recognition capacity in elderly and closed-head injury subjects with clinical memory deficits. *Journal of Clinical and Experimental Neuropsychology, 17*, 29 - 34.

Spikman, J. M., van Zomeren, A. H., & Deelman, B. G. (1996). Deficits of attention after closed head injury: slowness only? *Journal of Clinical and Experimental Neuropsychology, 18*(5), 755-767.

Spikman, J. M., Timmerman, M. E., van Zomeren, A. H., & Deelman, B. G. (1999). Recovery versus retest effects in attention after closed head injury. *Journal of Clinical and Experimental Neuropsychology, 21*(5), 585-605.

Spreen, O., & Strauss, E. (1991). *A Compedium of Neuropsychological Tests: Administration, Norms and Commentary.* New York: Oxford University Press.

Spreen, O., & Strauss, E. (1998). *Compedium of Neuropsychological Tests.* (2nd ed.). New York: Oxford University Press.

SPSS. (2002). *SPSS for Windows*. (Vol. Release 11.5). Chicago: SPSS Inc.

Squire, L. R. (1981). Two forms of human amnesia: an analysis of forgetting. *Journal of Neuroscience, 1*, 635 - 640.

Squire, L. R. (1986). Mechanisms of memory. *Science, 232*, 1612 - 1619.

Stambrook, M., Moore, A. D., Lubusko, A. A., Peters, L. C., & Blumenschein, S. (1993). Alternatives to the Glasgow Coma Scale as a quality of life predictor following traumatic brain injury. *Archives of Clinical Neuropsychology, 8*(2), 95-103.

Starkstein, S. E., Brandt, J., Folstein, S., Strauss, M., Berthier, M. L., Pearlson, G. D., Wong, D., McDonnell, A., & M., F. (1988). Neuropsychological and neuroradiological correlates in Huntington's disease. *Journal of Neurology, Neurosurgery, and Psychiatry, 51*, 1259 - 1263.

Stein, S. C., & Spettell, C. (1995). The head injury severity scale (HISS): a practical classification of closed-head injury. *Brain Injury, 9*(5), 437-444.

Stevens, M. M. (1982). Post concussion syndrome. *Journal of Neurosurgical Nursing, 14*(5), 239-244.

Stocchetti, N., Pagan, F., Calappi, E., Canavesi, K., Beretta, L., Citerio, G., Cormio, M., & Colombo, A. (2004). Inaccurate early assessment of neurological severity in head injury. *Journal of Neurotrauma, 21*(9), 1131-1140.

Strauss, D., & Finegan, J. (1990). Community support systems as they relate to sexuality for the head injured survivor. *Cognitive Rehabilitation, 8*(6), 8-11.

Strauss, M. E., Thompson, P., Adams, N. L., Redline, S., & Burant, C. (2000). Evaluation of a model of attention with confirmatory factor analysis. *Neuropsychology, 14*(2), 201-208.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643-662.

Study., S. H. I. M. (1977). Head injuries in Scottish hospitals. *Lancet, ii*, 696 - 698.

Stuss, D. T., Ely, P., Hugenholtz, H., Richard, M. T., Larochelle, S., Poirer, C. A., & Bell, I. (1985). Subtle neuropsychological deficits in patients with good recovery after closed head injury. *Neurosurgery, 17*, 41-47.

Stuss, D. T., & Benson, D. F. (1986). *The Frontal Lobes*. New York: Raven Press.

Stuss, D. T., Stethem, H., Hugenholtz, H., & Richard, M. T. (1989). Traumatic brain injury: a comparison of three clinical tests, and analysis of recovery. *The Clinical Neuropsychologist, 3*(2), 145-156.

Stuss, D. T. (1991). Self awareness and the frontal lobes: A neuropsychological perspective. In G. R. Goethals & J. Strauss (Eds.), *The self: An interdisciplinary approach* . New York: Springer-Verlag.

Stuss, D. T., Pogue, J., Buckle, L., & Bondar, J. (1994). Characterization of stability of performance in patients with traumatic brain injury: variability and consistency on reaction time tests. *Neuropsychology, 8*(3), 316-324.

Sunderland, A., Harris, J. E., & Baddeley, A. D. (1983). Do laboratory tests predict everyday memory? A neuropsychological study. *Journal of Verbal Learning and Verbal Behaviour, 22*, 341 - 357.

Sunderland, A., Harris, J. E., & Gleave, J. (1984). Memory failures in everyday life following severe head injury. *Journal of Clinical Neuropsychology, 6*, 127 - 142.

Swanson, J. M., Posner, M., Potkin, S., Bonforte, S., Ypupa, D., Fiore, C., Cantwell, D., & Crinella, F. (1991). Activating tasks for the study of visual-spatial attention in ADHD children: a cognitive anatomical approach. *Journal of Child Neurology, 6*(Supplement), s119-s127.

Sweeney, J. E. (1992). Nonimpact brain injury: Grounds for clinical study of the neuropsychological effects of acceleration forces. *The Clinical Neuropsychologist, 6*, 443 - 457.

Symonds, C. P., & Russell, W. R. (1943). Accidental head injuries. *Lancet, i*(7).

Teasdale, G., & Jennett, B. (1974). Assessment of coma and impaired consciousness: a practical scale. *Lancet, 2*, 81-84.

Thomsen, I. V. (1974). The patient with severe head injury and family. *Scandinavian Journal of Rehabilitation Medicine, 6*, 180-183.

Thomsen, I. V. (1977). Verbal learning in aphasic and non-aphasic patients with severe head injuries. *Scandinavian Journal of Rehabilitation Medicine, 9*, 73-77.

Thomsen, I. V. (1981). Neuropsychological treatment and longtime follow-up in an aphasic patient with very severe head trauma. *Journal of Clinical Neuropsychology, 3*(1), 43-51.

Thomsen, I. V. (1984). Late outcome of very severe blunt head trauma: a 10-15 year second follow-up. *Journal of Neurology, Neurosurgery, and Psychiatry, 47*, 260-268.

Thomsen, I. V. (1989). Do young patients have worse outcomes after severe blunt head trauma? *Brain Injury, 3*, 157 - 162.

Thone, A. I. T., Zysset, S., & von Cramon, D. Y. (1999). Retrieval of long-term memory in patients with brain injuries. *Journal of Clinical and Experimental Neuropsychology, 21*(6), 798 - 815.

Thurman, D. J., Sniezek, J. E., Johnson, D., Greenspan, A., & Smith, S. M. (1995). *Guidelines for surveillanceof central nervous system injury*. Atlanta, GA: US Department of Health and Human Services.

Thurman, D. J., Alverson, C., Dunn, K. A., Guerrero, J., & Sniezek, J. E. (1999). Traumatic brain injury in the United States: a public health perspective. *Journal of Head Trauma Rehabilitation, 14*(6), 602-615.

Tiret, L., Hausherr, E., Thicoipe, M., Garros, B., Maurette, P., Castel, J. P., & Hatton, F. (1990). The epidemiology of head trauma in Aquitaine (France), 1986: a community based study of hospital admissions and deaths. *International Journal of Epidemiology, 19*, 133-140.

Titchener, E. B. (1908). *Lectures on the Elementary Psychology of Feeling and Attention.* New York: Macmillan.

Treisman, A. M. (1960). Contextual cues in selective listening. *Quarterly Journal of Experimental Psychology, 12*, 242-248.

Treisman, A. M. (1964). Selective attention in man. *British Medical Bulletin, 20*(1), 12-15.

Treisman, A. M. (1970). Perception and recall of simultaneous speech stimuli. *Acta Psychologica, 33*, 132 - 148.

Treisman, A. M., & Fearnley, J. S. (1971). Can simultaneous speech stimuli be classified in parallel? *Perception and Psychophysics, 10*, 1 - 7.

Trenerry, M. R., Crosson, B., DeBoe, J., & Leber, W. R. (1989). *The Stroop Neuropsychological Screening Test.* Odessa, Florida: Psychological Assessment Resources.

Trexler, L. E., & Zappala, G. (1988). Neuropathological determinants of acquired attention disorders in traumatic brain injury. *Brain and Cognition, 8*, 291-302.

Tulving, E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson (Eds.), *Organization of memory* (pp. 381 - 403). New York: Academic Press.

Tulving, E. (1985). How many memory systems are there? *American Psychologist, 40*, 385 - 398.

Tyerman, A., & Humphry, M. (1984). Changes in self concept following severe head injury. *International Journal of Rehabilitation Research, 7*, 11-23.

Umilta, C. (1988). Orienting of attention. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology.* (Vol. 1, pp. 175 - 193): New York: Elsiever.

Uzzell, B. P., Langfitt, T. W., & Dolinskas, C. A. (1987). Influence of injury severity on quality of survival after head injury. *Surgical Neurology, 27*, 419-429.

van den Bosch, R. J., Rombouts, R. P., & van Asma, M. J. O. (1993). Subjective cognitive dysfunction in schizophrenic and depressed patients. *Comprehensive Psychiatry, 34*(2), 130 - 136.

van Zomeren, A. H., & Deelman, B. G. (1978). Long-term recovery of visual reaction time after closed head injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 41*, 452-457.

van Zomeren, A. H. (1981). *Reaction Time and Attention After Closed Head Injury*. Lisse: Swets & Zeitlinger B. V.

van Zomeren, A. L., Brouwer, W. H., & Deelman, B. G. (1984). Attentional deficits: the riddles of selectivity, speed and alertness. In N. Brooks (Ed.), *Closed Head Injury: Psychological, Social and Family Consequences* (pp. 74-107). Oxford: Oxford University Press.

van Zomeren, A. H., & Van den Berg, W. (1985). Residual complaints of patients two years after severe head injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 48*, 21-28.

van Zomeren, A. H., & Brouwer, W. H. (1987). Head injury and concepts of attention. In H. S. Levin, J. Grafman, & H. M. Eisenberg (Eds.), *Neurobehavioral Recovery from Head Injury* . Oxford: Oxford University Press.

van Zomeren, A. H., & Brouwer, W. H. (1992). Assessment of attention. In J. R. Crawford, D. M. Parker, & W. W. McKinlay (Eds.), *A handbook of neuropsychological assessment* (pp. 241-266). Hove (UK): Lawrence Erlbaum Associates.

van Zomeren, A. H., & Brouwer, W. H. (1994). Assessment of attention. In J. R. Crawford (Ed.), *A Handbook of Neuropsychological Assessment* .

Vanderploeg, R. D. (2000). *Clinician's guide to neuropsychological assessment.* Mahwah, NJ: Lawrence Erlbaum.

Varney, N. R., & Menefee, L. (1993). Psychosocial and executive deficits following closed head injury: implications for orbital frontal cortex. *Journal of Head Trauma Rehabilitation, 8*, 32-44.

Veltman, J. C., Brouwer, W. H., van Zomeren, A. H., & van Wolffelaar, P. C. (1996). Central executive aspects of attention in subacute severe and very severe closed head injury patients: Planning, inhibition, flexibility, and divided attention. *Neuropsychology, 10*(3), 357 - 367.

Verger, K., Junque, C., Levin, H. S., Jurado, M. A., Parez-Gomez, M., Bartres-Faz, D., Barrios, M., Alvarez, A., Bartumeus, F., & Mercader, J. M. (2001). Correlation of atrophy measures on MRI with neuropsychological sequelae in children and adolescents with traumatic brain injury. *Brain Injury, 15*(3), 211 - 221.

Vogenthaler, D. R. (1987). An overview of head injury: its consequences and rehabilitation. *Brain Injury, 1*(1), 113-127.

Voller, B., Auff, E., Schnider, P., & Aichner, F. (2001). To do or not to do? Magnetic resonance imaging in mild traumatic brain injury. *Brain Injury, 15*(2), 107-115.

Walsh, K. W. (1985). *Understanding Brain Damage*. Edingburgh: Churchill-Livingstone.

Walsh, V., & O'Mara, S. M. (1994). A selection on attention: special issue on attention. *Cognitive Neuropsychology, 11*(2), 97-98.

Watt, K. J., & O'Carroll, R. E. (1999). Evaluating methods for estimating premorbid intellectual ability in closed head injury. *Journal of Neurology, Neurosurgery, and Psychiatry, 66*, 474 - 479.

Weber, A. M. (1990). A practical clinical approach to understanding and treating attentional problems. *Journal of Head Trauma Rehabilitation, 5*(1), 73-85.

Wechsler, D. (1987). *Wechsler memory Scale - Revised.* San Antonio. TX: The Psychological Corporation.

Wehman, P., Kregel, J., Sherron, P., Nguyen, S., Kreutzer, J., Fry, R., & Zasler, N. (1993). Critical factors associated with the successful supported employment placement of patients with sever traumatic brain injury. *Brain Injury, 7*(1), 31-44.

Weinberg, J., & Diller, L. (1968). *On reading newspapers by hemiplegics - denial or visual disability.* Paper presented at the Proceedings of the 76th annual convention of the American Psychological Association.

Weinberg, J., Diller, L., Gerstman, L., & Schulman, P. (1972). Digit span in right and left hemiplegics. *Journal of Clinical Psychology, 28*, 361.

Whyte, J., Polansky, M., Fleming, M., Coslett, H. B., & Cavallucci, C. (1995). Sustained arousal and attention after traumatic brain injury. *Neuropsychologia, 33*(7), 797-813.

Whyte, J. (1996). Attentional function after TBI: what's impaired, what's preserved, and why? *International Perspectives in Traumatic Brain Injury*, 43.

Whyte, J., Hart, T., Laborde, A., & Rosenthal, M. (1998). Rehabilitation of the patient with traumatic brain injury. In J. A. Delisa (Ed.), *Rehabilitation Medicine: Principles and Practice* (3rd ed., pp. 1191-1239). Philadelphia: Lippincott.

Whyte, J., Schuster, K., Polansky, M., Adams, J., & Coslett, H. B. (2000). Frequency and duration of inattentive behaviour after traumatic brain injury: effects of distraction, task, and practice. *Journal of the International Neuropsychological Society, 6*, 1-11.

Wiedmann, K. D., Wilson, J. T. L., Wyper, D., Hadley, D. M., Teasdale, G. M., & Brooks, D. N. (1989). SPECT cerebral blood flow, MR imaging, and neuropsychological findings in traumatic head injury. *Neuropsychology, 3*, 267-281.

Wilkins, A. J., Shallice, T., & McCarthy, R. (1987). Frontal lesions and sustained attention. *Neuropsychologia, 25*(2), 359-365.

Williamson, D. J. G., Scott, J. G., & Adams, R. L. (1996). Traumatic brain injury. In R. L. Adams, O. A. Parsons, J. L. Culbertson, & S. J. Nixon (Eds.), *Neuropsychology for Clinical Practice: Etiology, Assessment and Treatment of Common Neurological Disorders* (pp. 9-64). Washington, DC: American Psychological Press.

Wilson, B. A., Cockburn, J., & Halligan, P. (1987). *Behavioural Inattention Test.* Titchfield: Thames Valley Test Co.

Wilson, B. A. (1987). *Rehabilitation of memory.* New York: Guilford Press.

Wilson, J. T. L. (1990a). Significance of MRI in clarifying whether neuropsychological deficits after head injury are organically based. *Neuropsychology, 4*, 261-269.

Wilson, J. T. L. (1990b). The relationship between neuropsychological function and brain damage detected by neuroimaging after closed head injury. *Brain Injury, 4*, 349-363.

Wilson, B. A., Vizor, A., & Bryant, T. (1991). Predicting severity of cognitive impairment after severe head injury. *Brain Injury, 5*, 189 -197.

Wilson, B. A. (1991). Long-term prognosis of patients with severe memory disorders. *Neuropsychological Rehabilitation, 1*(2), 117-134.

Wilson, J. T. L., & Wyper, D. (1992). Neuroimaging and neuropsychological functioning following closed head injury: CT, MRI, SPECT. *Journal of Head Trauma Rehabilitation, 7*(4), 29-39.

Wilson, B., & Moffatt, N. (1992). *Clinical management of memory problems.* (2nd ed.). San Diego, CA: Singular Publishing Group.

Wilson, B. A., Alderman, N., Burgess, P. W., Emslie, & Evans. (1996). *Behavioural assessment of the Dysexecutive Syndrome.* Bury St Edmunds: Thames Valley Test Company.

Wood, R. L. (1987). *Brain Injury Rehabilitation: A Neurobehavioural Approach.* Rockville: Aspen.

Woodward, A., Dorsch, M. M., & Simpson, D. (1984). Head injuries in country and city. A study of hospital separations in South Australia. *Medical Journal of Australia, 141*, 13-17.

Worden, F. G. (1966). Attention and auditory electrophysiology. In E. Stellar & J. M. Sprague (Eds.), *Progress in physiological psychology* (pp. 45 - 116). New York: Academic Press.

Workinger, M. S., & Netsell, R. (1992). Restoration of intelligible speech 13 years post-head injury. *Brain Injury, 6*, 183 - 188.

Wright, M. J., Burns, R. J., Geffen, L. B., & Geffen, G. M. (1990). Covert orientation of visual attention in parkinson's disease: an impairment in the maintenance of attention. *Neuropsychologia, 28*(2), 151-159.

Wright, M. J., Cremona-Meteyard, S. L., Geffen, L. B., & Geffen, G. M. (1994). The effects of closed head injury, senile dementia of the alzheimer's type, and parkinson's disease on covert orientation of visual attention. *Australian Journal of Psychology, 46*(2), 63-72.

Yantis, S., & Jonides, J. (1990). Abrupt visual onsets and selective attention: voluntary versus automatic allocation. *Journal of Experimental Psychology: Human Perception and Performance., 16*(1), 121 - 134.

Yokota, H., Kurokawa, A., Otsuka, T., Kobayashi, S., & Nakazawa, S. (1991). Significance of magnetic resonance imaging in acute head injury. *Journal of Trauma-Injury Infection and Critical Care, 31*(3), 351 - 357.

Yudofsky, S. C., & Hales, R. E. (1992). *American Psychiatric Press textbook of neuropsychiatry.* (2nd ed.). Washington, D.C.: American Psychiatric Press.

Zakzanis, K.K. (2001). Statistics to tell the truth, the whole truth, and nothing but the truth: formulae, illustrative numerical examples, and heuristic interpretation of effect size analyses for neuropsychological researchers. *Archives of Clinical Neuropsychology, 15*(2), 115-136.

Zasler, N. D. (1999). Posttraumatic headache: Caveats and controversies. *Journal of Head Trauma Rehabilitation, 14*(1), 1-8.

Zec, R. F., Zellers, D., Belman, J., Miller, J., Matthews, J., Ferneau-Belman, D., & Robbs, R. (2001). Long-term consequences of severe closed head injury on episodic memory. *Journal of Clinical and Experimental Neuropsychology, 23*(5), 671-691.

Zoccolotti, P., Matano, A., Deloche, G., Cantagallo, A., Passadori, A., Leclercq, M., Braga, L., Cremel, N., Pittau, P., Renom, M., Rousseaux, M., Truche, A., Fimm, B., & Zimmermann, P. (2000). Patterns of attentional impairment following closed head injury: a collaborative European study. *Cortex, 36*, 93-107.

Zoltan, B. (1990). Remediation of visual-perceptual and perceptual-motor deficits. In M. Rosenthal, E. R. Griffith, M. R. Bond, & J. D. Miller (Eds.), *Rehabilitation of the Adult and Child with Traumatic Brain Injury* (Second Edition ed.,). Philadelphia: F. A. Davis.

Zubin, J. (1975). Problem of attention in schizophrenia. In M. L. Kiettzman, S. Sutton, & J. Zubin (Eds.), *Experimental Approaches to Psychopathology* . New York: Academic Press.

9.0 Reprints of Published Papers

Bate, A.J., Mathias, J.L. & Crawford, J.R. (2001) The covert orienting of visual attention following severe traumatic brain injury.
Journal of Clinical and Experimental Neuropsychology, v. 23(3), pp. 386-398

Bate, A.J., Mathias, J.L. & Crawford, J.R. (2001) Performance on the test of everyday attention and standard tests of attention following severe traumatic brain injury.
The Clinical Neuropsychologist, v. 15(3), pp. 405-422

10.0 Appendices

10.1 Study 1

10.1.1 Analysis 1.1 COAT (Horizontal) Overall Analysis

	df	F	p	*Partial eta squared*
Group	1,67	8.89	.004	.117
Cue Type	2,134	7.39	.001	.099
Cue-Target-Interval (CTI)	2,134	45.52	.000	.405
Task Type	1,67	0.44	.511	.006
Group x Cue Type	2,134	0.17	.846	.002
Group x CTI	2,134	0.38	.685	.006
Group x Task Type	1,67	0.06	.804	.001
Group x Cue Type x CTI	4,268	0.82	.514	.012
Group x Cue Type x Task Type	2,134	0.42	.655	.006
Group x CTI x Task Type	2,134	2.34	.100	.034
Group x Cue Type x CTI x Task Type	4,268	1.43	.223	.021

Data File: COATALLX
Syntax File: Analysis1-COATHor

10.1.2 Analysis 1.2 Language Task (COAT – Horizontal)

	df	F	p	*Partial eta squared*
Group	1,68	19.82	.000	.226
Task Type	1,68	54.51	.000	.445
Group x Task Type	1,68	11.86	.001	.148

Data File: AttntMg
Syntax File: Analysis1A-LangHor

10.2 Study 2

10.2.1 Analysis 2.1 COAT (Vertical) Overall Analysis

	df	F	p	Partial eta squared
Group	1,67	4.22	.044	.059
Cue Type	2,134	13.38	.000	.166
Cue-Target-Interval (CTI)	2,134	20.25	.000	.232
Task Type	1,67	2.13	.149	.031
Group x Cue Type	2,134	6.53	.002	.089
Group x CTI	2,134	1.26	.287	.018
Group x Task Type	1,67	.004	.947	.000
Group x Cue Type x CTI	4,268	3.67	.006	.052
Group x Cue Type x Task Type	2,134	3.38	.037	.048
Group x CTI x Task Type	2,134	4.45	.013	.062
Group x Cue Type x CTI x Task Type	4,268	1.14	.340	.017

Data File: COATALLX
Syntax File: Analysis2-COATVer

10.2.2 Analysis 2.2 COAT (Vertical) Benefit

	df	F	p	Partial eta squared
Group	1,67	6.19	.015	.085
Benefit	1,67	11.12	.001	.142
Cue-Target-Interval	2,134	23.42	.000	.259
Task Type	1,67	1.96	.166	.028
Group x Benefit	1,67	5.33	.024	.074
Group x Benefit x CTI	2,134	5.60	.005	.077
Group x Benefit x Task Type	1,67	4.62	.035	.064
Group x Benefit x CTI x Task Type	2,134	2.10	.126	.030

Data File: COATALLX
Syntax File: Analysis2-COATVer

10.2.3 Analysis 2.3 COAT (Vertical) Cost

	df	F	p	**Partial eta squared**
Group	1,67	2.67	.107	.038
Cost	1,67	7.24	.009	.097
Cue-Target-Interval	2,134	18.65	.000	.218
Task Type	1,67	0.81	.370	.012
Group x Cost	1,67	3.60	.062	.051
Group x Cost x CTI	2,134	0.06	.941	.001
Group x Cost x Task Type	1,67	3.08	.084	.044
Group x Cost x CTI x Task Type	2,134	0.49	.616	.007

Data File: COATALLX Syntax File: Analysis2-COATVer

10.2.4 Analysis 2.4 COAT (Vertical) Validity

	df	F	p	Partial eta squared
Group	1,67	4.06	.048	.057
Validity	1,67	17.76	.000	.209
Cue-Target-Interval	2,134	17.42	.000	.206
Task Type	1,67	3.76	.057	.053
Group x Validity	1,67	8.67	.004	.115
Group x Validity x CTI	2,134	5.48	.005	.076
Group x Validity x Task Type	1,67	0.74	.394	.011
Group x Validity x CTI x Task Type	2,134	1.61	.204	.023

Data File: COATALLX
Syntax File: Analysis2-COATVer

10.2.5 Analysis 2.5 Language Task (COAT Vertical)

	df	F	p	*Partial eta squared*
Group	1,68	17.65	.000	.206
Task Type	1,68	52.00	.000	.433
Group x Task Type	1,68	10.91	.002	.138

Data File: AttntMg
Syntax File: Analysis2A-LangVer

10.3 Study 3

10.3.1 Analysis 3.1 Endogenous vs Exogenous (Overall Analysis)

	df	F	p	*Partial eta squared*
Group	1,19	4.52	.047	.192
Cue Type	2,38	1.19	.314	.059
Cue-Target-Interval (CTI)	1,19	0.93	.348	.046
Task Type	1,19	0.13	.726	.007
Group x Cue Type	2,38	0.56	.575	.029
Group x CTI	1,19	2.25	.150	.106
Group x Task Type	1,19	.005	.943	.000
Group x Cue Type x CTI	2,38	.133	.876	.007
Group x Cue Type x Task Type	2,38	2.26	.119	.106
Group x CTI x Task Type	1,19	0.39	.538	.020
Group x Cue Type x CTI x Task Type	2,38	1.12	.336	.056

Data File: ExogEnd1
Syntax File: Analysis3-ExogVsEndog

10.3.2 Analysis 3.2 Endogenous vs Exogenous (Validity Effect)

	df	F	p	Partial eta squared
Group	1,19	4.67	.044	.197
Validity	1,19	0.34	.567	.018
Cue-Target-Interval	1,19	0.68	.419	.035
Task Type	1,19	0.16	.698	.008
Group x Validity	1,19	0.10	.753	.005
Group x Validity x CTI	1,19	0.19	.665	.010
Group x Validity x Task Type	1,19	1.46	.241	.071
Group x Validity x CTI x Task Type	1,19	1.91	.183	.091

Data File: ExogEnd1
Syntax File: Analysis3-ExogVsEndog

10.4 Study 4 Established neuropsychological measures and the TEA

10.4.1 Analysis 4.1 Matching Variables

	df	F	p	Partial eta squared
Age	1,68	.260	.612	.004
Education	1,68	1.702	.196	.025
NART-R	1,68	7.15	.009	.095

Data File: AttntMg

10.4.2 Analysis 4.2 Neuropsychological Measures (series of Univariate ANOVAs)

	df	F	p	Partial eta squared
Colour Word (CW)	1,67	23.54	.000	.260
Modified Colour Word (IV)	1,67	41.87	.000	.385
Interference Effect (CWC)	1,67	3.79	.056	.051
Modified Interference Effect (IVC)	1,67	2.87	.095	.041
SDMT Oral – Correct (SDMTOC)	1,68	33.69	.000	.331
SDMT Written - Correct (SDMTWC)	1,68	34.36	.000	.336
Ruff Controlled Correct (RUFCONC)	1,68	21.07	.000	.237
Ruff Automatic Correct (RUFAUTC)	1,68	25.06	.000	.269
Ruff Total Correct (RUFCOR1)	1,68	24.45	.000	.264
PASAT 2.4 Correct (COR24)	1,66	6.26	.015	.087
PASAT 2.0 Correct (COR20)	1,66	7.58	.008	.103
PASAT 1.6 Correct (COR16)	1,63	13.93	.000	.181
PASAT 1.2 Correct (COR12)	1,63	17.40	.000	.216

Data File: AttntMg

10.4.3 Analysis 4.3 PASAT Presentation Rate

	df	F	p	Partial eta squared
Group	1,63	11.83	.001	.158
Presentation Rate	3,189	149.67	.000	.704
Group x Presentation Rate	3,189	1.03	.381	.016

Data File: AttntMg
Syntax File: Analysis4.2 Presentation-Rate

10.4.4 Analysis 4.4 TEA Measures (series of Univariate ANOVAs)

	df	F	p	Partial eta squared
Map Search (MS2RAW)	1,68	27.54	.000	.288
Elevator Counting (ECRAW)	1,68	.314	.577	.005
Visual Elevator 1 (VE1RAW)	1,68	3.06	.085	.043
Visual Elevator 2 (VE2RAW)	1,68	10.56	.002	.134
Elevator Counting with Reversal (ECRRAW)	1,58	4.63	.036	.074
Telephone Search (TSRAW)	1,68	23.39	.000	.256
Telephone Search while Counting (TSCRAW)	1,68	2.86	.096	.040
Lottery (LOTRAW)	1,68	6.05	.016	.082

10.4.5 Analysis 4.5 Relationship between TEA and established measures of attention – Pearson correlation coefficients

Refer to Table 4.4, page 168

10.4.6 Analysis 4.7 Differences in the Rating Scale of Attentional behaviour between the two groups.

	df	F	p	Partial eta squared
Group	1,57	8.227	.006	.126
Group x Informant	1,57	14.011	.000	.197

Data File : Scales1
Syntax File: Rating Scales Study 4

10.5 Study 5

10.5.1 Analysis 5.1 COAT (vertical) Cross-sectional overall analysis Early TBI vs Late TBI

A 4 –way Group (Early TBI, Late TBI) by Cue-Type (valid, neutral, invalid) by Cue-Target Interval (150, 550, 1000 ms) by Task-Type (single, dual) repeated measures ANOVA.

	df	F	p	Partial eta squared
Group	1,31	.122	.730	.004
Cue Type	2,62	8.21	.001	.209
Cue-Target-Interval (CTI)	2,62	18.51	.000	.374
Task Type	1,31	.787	.382	.025
Group x Cue Type	2,62	2.38	.101	.071
Group x CTI	2,62	3.83	.027	.110
Group x Task Type	1,31	2.63	.115	.078
Group x Cue Type x CTI	4,124	2.06	.090	.062
Group x Cue Type x Task Type	2,62	1.19	.311	.037
Group x CTI x Task Type	2,62	.372	.691	.012
Group x Cue Type x CTI x Task Type	4,124	.825	.511	.026

Data File:	COATALLX
Syntax File:	COATVS&DRM

10.5.2 Analysis 5.2 COAT (vertical) Cross-sectional Benefit analysis Early TBI vs Late TBI

A 4 –way Group (Early TBI, Late TBI) by Benefit (valid, neutral) by Cue-Target Interval (150, 550, 1000 ms) by Task-Type (single, dual) repeated measures ANOVA.

	df	F	p	Partial eta squared
Group	1,33	0.14	.708	.004
Benefit	1,33	7.27	.011	.180
Cue-Target-Interval	2,66	25.14	.000	.432
Task Type	1,33	0.18	.677	.005
Group x Benefit	1,33	3.10	.088	.086
Group x Benefit x CTI	2,66	0.28	.757	.008
Group x Benefit x Task Type	1,33	1.24	.274	.036
Group x Benefit x CTI x Task Type	2,66	0.97	.386	.028

Data File:	COATALLX
Syntax File:	BenefitVCross

10.5.3 Analysis 5.3 COAT (vertical) Cross-sectional Cost analysis Early TBI vs Late TBI

A 4 –way Group (Early TBI, Late TBI) by Cost (neutral, invalid) by Cue-Target Interval (150, 550, 1000 ms) by Task-Type (single, dual) repeated measures ANOVA.

	df	F	p	Partial eta squared
Group	1,33	.000	.993	.000
Cost	1,33	5.64	.024	.146
Cue-Target-Interval	2,66	15.037	.000	.313
Task Type	1,33	.210	.650	.006
Group x Cost	1,33	.043	.837	.001
Group x Cost x CTI	2,66	2.271	.111	.064
Group x Cost x Task Type	1,33	1.486	.232	.043
Group x Cost x CTI x Task Type	2,66	.673	.514	.020

Data File: COATALLX
Syntax File: CostVCross

10.5.4 Analysis 5.4 COAT (vertical) Cross-sectional Validity analysis Early TBI vs Late TBI

A 4 –way Group (Early TBI, Late TBI) by Validity (valid, invalid) by Cue-Target Interval (150, 550, 1000 ms) by Task-Type (single, dual) repeated measures ANOVA.

	df	F	p	Partial eta squared
Group	1,33	.106	.746	.003
Validity	1,33	11.351	.002	.256
Cue-Target-Interval	2,66	24.801	.000	.429
Task Type	1,33	.920	.344	.027
Group x Validity	1,33	1.755	.194	.051
Group x Validity x CTI	2,66	2.569	.084	.072
Group x Validity x Task Type	1,33	.002	.968	.000
Group x Validity x CTI x Task Type	2,66	1.824	.169	.052

Data File: COATALLX
Syntax File: ValidityVCross

10.5.5 Analysis 5.5 Language Task (horizontal COAT)

	df	F	p	*Partial eta squared*
Group	1,33	.326	.572	.010
Task Type	1,33	51.093	.000	.608
Group x Task Type	1,33	.603	.443	.018

Data File: AttntMg Syntax File:Language(Hor)Cross-Sec

10.5.6 Analysis 5.6 Language Task (vertical COAT)

	df	F	p	*Partial eta squared*
Group	1,33	.832	.368	.025
Task Type	1,33	51.189	.000	.608
Group x Task Type	1,33	1.383	.248	.040

Data File: AttntMg
Syntax File: Language(Vert)Cross-Sec

10.5.7 Analysis 5.7 Neuropsychological Measures

	df	F	p	Partial eta squared
Stroop Colour Word (CW)	1,32	.926	.343	.028
Modified Colour Word (MCW)	1,32	.031	.861	.001
SDMT Written Correct (SDMTWC)	1,33	2.42	.129	.068
SDMT Oral Correct (SDMTOC)	1,33	3.89	.057	.105
Ruff Controlled Correct (RUFCONC)	1,33	2.30	.139	.065
Ruff Automatic Correct (RUFAUTC)	1,33	1.982	.169	.057
Ruff Total Correct (RUFCOR1)	1,33	2.209	.147	.063
PASAT 2.4 Correct (COR24)	1,32	.001	.976	.000
PASAT 2.0 Correct (COR20)	1,32	.075	.786	.002
PASAT 1.6 Correct (COR16)	1,30	.000	.992	.000
PASAT 1.2 Correct (COR12)	1,30	.000	1.000	.000

Data File: AttntMg
Series of univariate ANOVAs

10.5.8 Analysis 5.8 TEA Measures (series of Univariate ANOVAs)

	df	F	p	Partial eta squared
Map Search (MS2RAW)	1,33	.001	.973	.000
Visual Elevator 2 (VE2RAW)	1,33	.072	.790	.002
Elevator Counting with Reversal (ECRRAW)	1,26	.159	.693	.006
Telephone Search (TSRAW)	1,33	.195	.662	.006
Lottery (LOTRAW)	1,33	2.813	.103	.079

Data File: AttntMg
Series of univariate ANOVAs

10.5.9 Analysis 5.9 Differences in the Rating Scale of Attentional behaviour between the Early and Late TBI groups.

	df	F	p	Partial eta squared
Self Report				
Group	1,32	0.38	.541	.012
Significant-Other Report				
Group	1,27	10.36	.003	.277

Data File : ScalesCross
Univariate ANOVAs

10.6 Study 6 Longitudinal Analysis (Retest)

10.6.1 Analysis 6.1 COAT (vertical) Longitudinal overall analysis

	df	F	p	Partial eta squared
Group	2,31	2.011	.151	.115
Cue Type	2,62	96.86	.000	.758
Cue-Target-Interval (CTI)	2,62	119.47	.000	.794
Task Type	1,31	2.32	.138	.070
Time	1,31	4.73	.037	.132
Group x Cue Type	4,62	3.92	.007	.202
Group x CTI	4,62	1.89	.124	.109
Group x Task Type	2,31	1.84	.175	.106
Group x Time	2,31	.225	.800	.014
Group x Cue Type x CTI	8,124	2.26	.027	.127
Group x Cue Type x Task Type	4,62	.497	.738	.031
Group x Cue-Type x Time	4,62	.300	.877	.019
Group x CTI x Task Type	4,62	1.34	.264	.080
Group x CTI x Time	4,62	1.33	.271	.079
Group x Task Type x Time	2,31	.051	.950	.003
Group x Cue Type x CTI x Task Type	8,124	.908	.512	.055
Group x Cue Type x CTI x Time	8,124	1.14	.343	.068
Group x Cue Type x Task Type x Time	4,62	2.25	.074	.127
Group x CTI x Task Type x Time	4,62	.651	.628	.040
Group x Cue Type x CTI x Task Type x Time	8,124	.665	.721	.041

Data File: COATVR
Syntax File: COATSIRDIRRMVert

10.6.2 Analysis 6.2 COAT (Vertical) Longitudinal Benefit analysis

	df	F	p	Partial eta squared
Group	2,31	2.62	.089	.144
Benefit	1,31	128.20	.000	.805
Cue-Target-Interval	2,62	141.11	.000	.820
Task Type	1,31	2.46	.127	.073
Time	1,31	3.74	.062	.108
Group x Benefit	2,31	.034	.967	.002
Group x Time	2,31	.224	.800	.014
Group x Benefit x CTI	4,62	2.19	.080	.124
Group x Benefit x Task Type	2,31	1.48	.243	.087
Group x Benefit x Time	2,31	.422	.659	.027
Group x Benefit x CTI x Task Type	4,62	.790	.536	.048
Group x Benefit x CTI x Time	4,62	.133	.970	.008
Group x Benefit x Task Type x Time	2,62	2.57	.093	.142
Group x Benefit x CTI x Task Type x Time	4,62	1.08	.375	.065

Data File: COATVR Syntax File:COATSIRDIRRMVert

10.6.3 Analysis 6.3 COAT (Vertical) Longitudinal Cost analysis

	df	F	p	Partial eta squared
Group	2,31	1.70	.199	.099
Cost	1,31	34.64	.000	.528
Cue-Target-Interval	2,62	112.81	.000	.784
Task Type	1,31	3.02	.092	.089
Time	1,31	4.46	.043	.126
Group x Cost	2,31	5.95	.007	.277
Group x Time	2,31	.208	.814	.013
Group x Cost x CTI	4,62	1.94	.114	.111
Group x Cost x Task Type	2,31	.312	.734	.020
Group x Cost x Time	2,31	.023	.977	.001
Group x Cost x CTI x Task Type	2,134	0.49	.616	.007
Group x Cost x CTI x Time	4,62	1.19	.323	.072
Group x Cost x Task Type x Time	2,31	3.09	.060	.166
Group x Cost x CTI x Task Type x Time	4,62	.86	.491	.053

Data File: COATVR
Syntax File: COATSIRDIRRMVert

10.6.4 Analysis 6.4 COAT (Vertical) Validity

	df	F	p	Partial eta squared
Between Subject Effects				
Group	2,31	1.78	.185	.103
Within Subject Effects				
Validity	1,31	127.02	.000	.804
Cue-Target-Interval	2,62	100.98	.000	.765
Task Type	1,31	1.44	.239	.044
Time	1,31	6.11	.019	.165
Group x Validity	2,31	3.89	.031	.200
Group x Time	2,31	.249	.781	.016
Group x Validity x CTI	4,62	2.73	.037	.150
Group x Validity x Task Type	2,31	0.09	.914	.006
Group x Validity x Time	2,31	.843	.440	.052
Group x Validity x CTI x Task Type	4,62	1.42	.239	.084
Group x Validity x CTI x Time	4,62	1.77	.146	.103
Group x Validity x Task Type x Time	2,31	.385	.684	.024
Group x Validity x CTI x Task Type x Time	4,62	.084	.984	.006

Data File: COATVR
Syntax File: COATSIRDIRRMVert

10.6.5 Analysis 6.5 Language Task (COAT Horizontal)

A Group (Early TBI, Late TBI, Control) by Time (initial, retest) repeated measures ANOVA

	df	F	p	Partial eta squared
Group	2,32	9.80	.000	.380
Time	1,32	13.66	.001	.299
Group x Time	2,32	4.99	.013	.238

Data File: Retest
Syntax File:Language Task retest

10.6.6 Analysis 6.6 Language Task (COAT Vertical)

A Group (Early TBI, Late TBI, Control) by Time (initial, retest) repeated measures ANOVA

	df	F	p	Partial eta squared
Group	2,32	15.89	.000	.498
Time	1,32	7.16	.012	.183
Group x Time	2,32	3.35	.048	.173

Data File: Retest
Syntax File:Language Task retest

10.7 Study 7

10.7.1 Analysis 7.1 Matching Variables

	df	F	p	Partial eta squared
Age	1,68	.260	.612	.004
Education	1,68	1.702	.196	.025
NART-R	1,68	7.15	.009	.095

Data File: AttntMg

10.7.2 Analysis 7.2 Differences between the TBI and Control groups on the WMS-R sub-tests

	df	F	p	Partial eta squared
Mental Control	1,66	.031	.860	.000
Figural Memory	1,66	10.949	.002	.142
Logical Memory 1	1,66	6.054	.016	.084
Visual Paired Associates 1	1,66	8.183	.006	.110
Verbal Paired Associates 1	1,66	5.226	.025	.073
Visual Reproduction 1	1,66	7.138	.009	.098
Forward Digit Span	1,66	2.652	.108	.038
Backward Digit Span	1,66	3.300	.074	.046
Visual Memory Span	1,66	.512	.477	.008
Logical Memory 2	1,66	12.405	.001	.158
Visual Paired Associates 2	1,66	12.117	.001	.155
Verbal Paired Associates 2	1,66	5.678	.020	.079
Visual Reproduction 2	1,66	9.773	.003	.129

Data File: AttntMg

10.7.3 Analysis 7.4 Correlation between the Attention/Concentration Index and the WMS-R Indices for the TBI group.

Date File: Attnt1MgTBI

Output is reported in Table 6.5, p271

10.7.4 Analysis 7.5 Differences between the TBI and Control groups on WMS-R index scores with Map Search and PASAT (1.6) as covariates

	df	F	p	Partial eta squared
Verbal Memory	1,59	0.164	.687	.003
Visual Memory	1,59	4.872	.031	.076
General Memory	1,59	0.566	.455	.010
Attention / Concentration Index	1,59	1.034	.313	.017
Delayed Memory	1,59	1.185	.281	.020

Data File: AttntMg