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Traumatic Brain Injury and Mental Fatigue: Effects on Executive Control

Jessica Dawn Fry

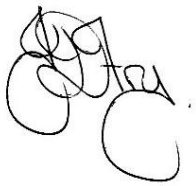
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Supervisor: Mrs Enid Schutte

A research project submitted in fulfillment of the requirements for the degree of MSc (by dissertation only) in the field of Psychology in the Faculty of Science, University of the Witwatersrand, Johannesburg, April 2009

Declaration

I declare that this research report is my own, unaided work. It has not been submitted before for any other degree or examination at this or any other university.



10/04/2009

Jessica Dawn Fry Date

Abstract

The present study was directed at an examination of the executive control of behaviour in both an organically compromised population and in an organically uncompromised population. It was tested whether behavioural manifestations may be linked to compromised executive control. This study also aimed to answer the question as to whether fatigue, as measured by a subjective questionnaire, negatively impacted on executive control. Executive control refers to the ability to sustain attentional capacity as required to regulate perceptual and motor processes in order to facilitate the inductive reasoning required to respond in an adaptive way to changing task demands (Baddeley & Logie, 1999, as cited in van der Linden, Frese & Meijman, 2003). It was operationalised as decreased cognitive flexibility and increased perseveration as measured by the Wisconsin Card Sorting Test (WCST). In complex tasks, executive control may become manifest as decreased flexibility. A simple memory task, the Forward Digit Span Test, was used as a control measure. This test examines immediate attention span or the ability to hold information in mind, which is thought to be a relatively automatic process. The Forward Digit Span Test was used as a control measure, because it was assumed that performance on this measure would not be affected by fatigue.

There were 30 individuals in the organically compromised group, with 15 individuals having been subjected to a fatigue condition and 15 having been subjected to a non-fatigue condition. There were 30 individuals in the organically uncompromised group, again with 15 individuals having been subjected to a fatigue condition and 15 individuals having been subjected to a non-fatigue condition. Thus, a control group of healthy individuals with no history of traumatic brain injury was included, adding to the power of the study.

Fatigue was induced through working for two hours on a range of cognitively demanding neuropsychological tasks. Fatigue was investigated through the use of a subjective, self-report fatigue rating scale, the Visual Analogue Scale of Fatigue. The results of this study showed that compared to non-fatigued participants, fatigued participants displayed more perseveration and reduced inductive reasoning on the WCST. This trend was consistent in both organically compromised and uncompromised individuals. Fatigue also affected performance on the simple memory task. These findings indicate compromised executive control under fatigue, which may explain the typical errors and sub-optimal performance that are often found in fatigued people. These findings also imply that not only executive control is affected; more automatic processes, such as the ability to hold information in mind also appear to be affected by fatigue. This study adds important information regarding the mechanisms and implications of fatigue on cognitive functioning.

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Dedication

I dedicate this manuscript to my loving parents, Mr Nicolas Kingsley and Mrs Helga Dorothea Fry. They have shown the most incredible support through the difficult times during the research process. I am truly grateful to them for making this opportunity possible.

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Theoretical and Conceptual Background

Introduction

This study had as its aim the examination of the executive control of behaviour. This was examined in both an organically compromised population and in an organically uncompromised population. In this study, organic compromise refers to individuals that have acquired a traumatic brain injury (TBI). Included in the study were individuals that had previously suffered either a moderate or a severe TBI. This study aimed to answer the question as to whether fatigue negatively impacts on executive control. Fatigue was measured by a subjective questionnaire. Decreased cognitive flexibility and increased perseveration as measured by the Wisconsin Card Sorting Test (WCST) were the indicators of executive control. In complex cognitive tasks, reduced executive control may become manifest as decreased flexibility. A simple, short-term memory task, the Forward Digit Span Test, was used as a comparison measure. This task was included because it was assumed that performance on the Forward Digit Span Test would not be affected by fatigue.

Data from 30 individuals who had sustained TBI was included in the organically compromised group, with 15 individuals having been subjected to a fatigue condition and 15 having been subjected to a non-fatigue condition. Fatigue, under the fatigue condition, was induced within the assessment session. Given that the analysis was based on the available data, there was no manipulation of an independent variable, nor was there any randomisation present. The data of the participants that met the inclusion criteria of this study were selected; thus, purposive sampling was utilised. For this reason, this research design is a non-experimental, ex-post facto design (Rosnow & Rosenthal, 1996).

A comparison group of individuals with no history of a TBI was included in this study. There were 30 individuals in the organically uncompromised group, again with 15 being subjected to a fatigue condition and 15 being subjected to a non-fatigue condition; thus, complying with a quasi-experimental research design (Rosnow & Rosenthal, 1996).

Non-fatigued participants completed the WCST at the beginning of the testing session, to minimise the risk of their being fatigued. The assumption that these individuals were not fatigued was verified through the application of the self-report fatigue instrument. In the fatigued groups, fatigue was induced through working for two hours on a range of different, cognitively demanding neuropsychological tasks. Subjective fatigue was investigated through the use of a subjective, self-report, fatigue rating scale, the Visual Analogue Scale of Fatigue.

The results showed that compared to the non-fatigued groups, fatigued participants displayed more perseveration and reduced inductive reasoning on the WCST. Fatigue also affected performance on the simple short-term memory task. These findings indicate compromised executive control under fatigue. The findings of his study also imply that it is not only executive control that is affected by fatigue; more automatic processes, such as the ability to hold information in mind, are affected by fatigue. These trends apply to both organically compromised and uncompromised individuals. This study adds important information regarding the mechanisms and implications of fatigue on cognitive functioning.

The rationale behind this investigation is that the effects of mental fatigue from an executive control perspective have only been studied explicitly by a few studies (van der Linden, Frese & Meijman, 2003). The complaint of fatigue after traumatic brain injury, regardless of severity, has been reported by many

studies. However, only a few studies have formally investigated the implications and mechanisms of fatigue on cognitive functions (Belmont, Agar, Hugeron, Gallais & Azouvi, 2006).

Fatigue is deemed to be important to understand, especially in terms of its affects on cognition, because fatigue after all severities of TBI is constraining in daily life. Fatigue has been reported to adversely impact on the rehabilitation process (Lee, Hicks & Nino-Murcia, 1991). Fatigue negatively impacts on the efficacy of interventions, including cognitive rehabilitation. It is important that fatigue be understood in the context of rehabilitative interventions and how it impacts on cognition in this context. This understanding of fatigue and its implications would lead to the increased efficacy of cognitive rehabilitative efforts. Fatigue has also been known to place restrictions on an uncompromised return to the workplace or school. Fatigue is thought to affect work and/or school performance; including in the domains of learning and memory. Thus, fatigue affects everyday functioning. For this reason, the individual may need some form of compensated work, tailored work or school requirements, fewer demands and responsibilities, as well as supervision or a structured programme to enable them to work efficiently.

In terms of the structure of this report, the literature review begins with definitions and explanations of traumatic brain injury (TBI). The classifications of TBI are then provided. The deficits that result from TBI are outlined, including the post-concussion syndrome (PCS). One of the symptoms of PCS, fatigue, is elaborated on in detail, with definitions provided. The deficits that result from fatigue are then described. Measures that assess fatigue are then discussed. The literature review goes on to discuss fatigue in terms of it’s effects on executive functioning and executive control. Towards the end of the literature review, a rationale and research questions are given. The research report then goes on

to Methods, which outlines the aims of the research and the research design. The participants, procedures and instruments are then discussed. The last section of methods includes a brief description of the ethical considerations of this report. The report then moves on to a discussion of the results of the study. The Discussion follows, including an examination of the strengths of this research, the weaknesses of this research and suggestions for future research and lastly, conclusions are drawn.

Literature Review

Traumatic Brain Injury

Definition of Traumatic Brain Injury

Traumatic brain injury is defined as "any brain damage, even trifling, related to an impact on the brain" (Belmont et al., 2006, p.370). Traumatic brain injury (TBI) is also referred to as acquired brain injury. TBI results from trauma to the head and may cause substantial disability and/or morbidity. TBI occurs when a sudden trauma damages the brain and disrupts the functioning of the brain.

Epidemiology of Traumatic Brain Injury

Nell and Ormond-Brown (1991) conducted a study on the epidemiology of TBI in Johannesburg, South Africa. The authors reported an overall annual incidence of 316 per 100, 000 individuals, with an overall incidence of fatal TBI of 80 per 100, 000 people. A more recent South African estimate is that out of a population of approximately 48 million people, between 9, 000 – 11, 000 individuals per year are victims of TBI. This estimate includes 5 – 10% with severe TBI, which could lead to long-term disability. There are more than 1.5 million cases of TBI in the USA per annum out of a population of approximately 305 million people (National Centre for Injury Prevention and Control, 2003), most of which are categorised

as mild TBI. As a result of TBI in the United States, approximately 50, 000 people die; 230, 000 people are hospitalised and survive; and an estimated 90, 000 people experience the onset of long-term disability (Thurman, Alverson, Dunn, Guerrero & Sniezek, 1999). Javoyhey, Guerin and Chiron (2006) carried out an epidemiological study in France. This study investigated the incidence of severe TBI resulting specifically from road accidents. The authors reported an annual incidence of 13.7 per 100, 000 people. The international prevalence of TBI is reported to be greater in men (sex ratio 2:1) and in the age bracket 12 – 25 years of age (Headway information brochure, 2007).

Causes and Mechanisms of Traumatic Brain Injury

In terms of the causes of TBI, a TBI is typically caused by an excessive force or a blow to the head, or to a penetrating head injury (Chambers, Cohen, Hemminger, Prall & Nichols, 1996). It is reported that road traffic accidents represent the main cause of TBI. Sixty – 70% of cases of TBI are due to motor vehicle and pedestrian-vehicle accidents. There are, however, other causes of TBI. Traumatic brain injury may also be caused by falls (28%), being struck by or against objects (19%), or assaults (11%). Traumatic brain injury is divided into primary and secondary injury. The former, primary injury is induced by a mechanical force and occurs at the moment of the injury. The latter, secondary injury is not mechanically induced. Instead, secondary injury may be delayed from the moment of mechanical impact. Complicating matters, secondary injury may superimpose on a brain that is already affected by a primary injury (Smith, Meaney & Shull, 2003).

In terms of the mechanisms of TBI, there are two main mechanisms that may cause primary injury. The first is known as the direct or contact mechanism. This includes an object striking the head or the brain striking the inside of the skull as in the case of coup-countercoup injuries (Smith, Meaney & Shull,

2003). Consequences of the direct mechanism may include injury to the scalp, fracture of the skull and/or contusions of the brain. The second mechanism is known as the indirect or acceleration-deceleration mechanism. This mechanism results from the unrestricted movement of the head that may lead to shear, tensile and compressive strain, which can cause severe consequences, including intracranial haematoma, diffuse axonal injury and diffuse vascular injury (Povlishock, Becker, Cheng & Vaughn, 1983).

Diffuse axonal injury (DAI) is one of the most common and important pathologic features of TBI. Diffuse axonal injury constitutes predominantly microscopic damage. Unfortunately, DAI is often not visible on either computed tomography (CT) or magnetic resonance imaging (MRI) scans of the brain, which may lead to under-diagnosis of this important feature of TBI. The primary mechanical force that causes DAI is the rotational acceleration of the brain. This force results in the unrestricted movement of the brain inside the skull, which produces shearing and tensile forces. Consequently, neuronal axons can be pulled apart at the microscopic level and small blood vessels can burst. The rapid stretching of axons, which occurs under the shearing and tensile forces, is thought to damage the axonal cytoskeleton and therefore, disrupt normal functioning of neurons (Smith, Meaney & Shull, 2003).

As a result of axonal injury, localised transport failures may occur in the axon. This leads to the swelling and often the lysis (bursting) of the axon (Lighthall, Goshgarian & Pinderski, 1990). Further, the role of the release of excitatory neurotransmitters from the synapses of damaged axons as a cause of downstream cell loss is uncertain (Hayes & Dixon, 1994). Vascular injury, particularly due to DAI, can disrupt small veins, producing petechial haemorrhages, or local or focal oedema. The parasaggital deep white matter, spreading from the cortex to the brainstem, appears to be the primary distribution of injury.

Alexander (1995) notes that it is this pattern of damage in the parasaggital deep white matter that may be responsible for the predominance of attentional and executive deficits.

Secondary injury is delayed from the moment of impact and may occur hours or even days after the primary traumatic injury. It is reported that secondary injury may result from the local impairment or decline in the blood flow in the cerebrum. Decreases in cerebrospinal fluid are resultant from local oedema (swelling), haemorrhage and/or raised intracranial pressure. Due to inadequate perfusion of fluids within the brain, cellular ion pumps may fail. This in turn causes a cascade that involves the diffusion of intracellular calcium and sodium. The resultant cellular calcium and sodium overload may further contribute to the destruction of cells. The excessive release of excitatory amino acids, including glutamate and aspartate, further exacerbates the failure of the cellular calcium and sodium ion pumps. As the cascade continues, cells die, which in turn causes the formation of free radicals and proteolysis (destruction of proteins). These factors can ultimately cause or contribute to neuronal death. The exact role of the inflammatory response in secondary injury is not known. However, the inflammatory response is thought to contribute to neuronal damage and ultimately, death. Clinical conditions that are associated with the decrease in cerebral blood flow are arterial hypotension, hypoxemia, intracranial haemorrhage, malignant brain oedema and hyperthermia (Noppens & Brambrink, 2004).

Classification of Traumatic Brain Injury

In terms of the classification of the severity of TBI, there is no one set of universally accepted criteria (Jagoda & Riggio, 2005). Thus, a variety of scales may be sited in the literature for this purpose. The most widely used scale for the classification of the severity of TBI is the Glasgow Coma Scale (GCS). The GCS is used to assess a patient's level of consciousness and their level of neurologic function.

Scores on the GCS range from 3 to 15 out of a possible 15, where a score of 3 refers to a state of deep coma and a score of 15 refers to normal consciousness. The GCS consists of three sub-sections, each of which is scored separately and summed. These sub-sections are a) best motor response, b) best verbal response, and c) eye opening (see appendix 1). The severity of TBI according to the GCS grades mild TBI as scores ranging from 13-15, moderate TBI as scores ranging from 9-12 and severe TBI as scores ranging from 3-8 (Teasdale & Jennett, 1974).

The understanding of coma and consciousness is necessary to fully comprehend the GCS and in turn, the severity of TBI. Coma can be understood as a level of consciousness. Consciousness refers to the awareness of oneself and of one's surroundings. Consciousness is accompanied by neuronal activity within the whole cerebral cortex. Loss of consciousness is a normal occurrence during sleep, but is abnormal in injuries or diseases that affect the brain. Profound and often irreversible loss of consciousness may be caused by extensive destruction to the cerebrum or by localised lesions in certain parts of the brainstem that have extensive divergent projections to the cortex. An alert or wakeful state is typified by the generalised activity of the cerebral cortex. This only occurs when there is the adequate excitation of cortical neurons whose cell bodies are in the brainstem and thalamus. Bilateral destruction of the medial parts of the brainstem at or above the upper pontine levels will result in a state of irreversible coma. In order to maintain the conscious state, the integrity of the rostral pontine reticular formation and of the central tegmental tract is essential (Kiernan, 2005). The reticular activating system (RAS) is a network of neurons that controls wakefulness, as well as the alerting mechanisms that ready the individual to react. The RAS arouses the cerebral cortex; the intact functioning of this network is a precondition for conscious behaviour since it arouses the sleeping or inattentive organism (Roth, 2000). Damage to the RAS gives rise to both sleep disturbances and to global disorders of consciousness and

responsivity, including drowsiness, somnolence, stupor and coma (Green, 1987, as cited in Lezak, 1995). In other words, damage to the RAS will result in altered levels of consciousness (Roth, 2000).

In order to measure the severity of TBI by means of the GCS, the evaluation of both the depth and the duration of altered consciousness are required. Importantly, a single GCS score with no indication of when it was calculated and the status of other pertinent factors, including sedatives, blood alcohol level, intubation, facial injuries and anesthesia, can lead to the inaccurate assessment of the severity of the TBI. Indeed, it may take several GCS scores from the first 48-72 hours post-injury to establish the severity of the injury clearly. Individuals who enter the trauma system with little or no initial loss of consciousness, but who suffer a subsequent deterioration in mental status are likely to be misclassified by an early GCS score. This deterioration will usually take place within in the first 72 hours post-injury, possibly due to secondary injury resulting from a delayed haematoma (Lezak, 1995).

According to Greenwald, Burnett and Miller (2003), the duration of loss of consciousness (LOC) is also an indication of the measure of the severity of a TBI (see appendix 2). Mental status change or duration of LOC for less than 30 minutes is indicative of mild traumatic brain injuries. Mental status change or duration of LOC for between 30 minutes and 6 hours is typically associated with traumatic brain injuries of moderate severity. Mental status change or duration of LOC for longer than six hours is associated with severe traumatic brain injuries. It is important to note, however, that duration of LOC alone is a poor predictor of the outcome of a TBI, especially for people with brief – up to 30 minutes – of loss of consciousness.

Russell (1974, as cited in Lezak, 1995) is credited with the introduction of the concept of post-traumatic amnesia (PTA). This concept was later defined as the period of time elapsed from the onset of the injury to the moment when an individual can demonstrate continuous memory of what is occurring in their environment and what is happening around them. Patients who are in PTA show essentially no learning and cannot lay down new memories; and are confused as to events taking place around them. Even when patients slowly emerge from PTA, they will not have recall (contiguous PTA) or only a vague, patchy recall (discontiguous PTA) for the events that occurred during PTA and for the accident itself.

Some investigators rely on the duration of PTA as an indication of the severity of the injury to the brain. This is due to the fact that PTA duration has been shown to correlate well with GCS ratings. Brooks (1989, as cited in Lezak, 1995) observed that the duration of PTA typically lasts about four times the length of coma. Indeed, PTA begins at the time of the onset of the injury and includes the coma period. Mild TBI is typically associated with a duration of PTA of up to one hour after the injury. As coma duration increases, moderate head injuries are typically associated with a duration of PTA of between 1 – 24 hours. Lastly, severe TBI is associated with PTA lasting longer than one day, with no maximum duration stipulated. It is generally agreed among members of the scientific community that PTA does not come to an end when the patient first begins to register experiences again. Instead, PTA is generally considered to have ended only when registration of events and experiences is continuous for several consecutive days. Post-traumatic amnesia can be used to predict cognitive status quo two years post-injury, yet failures to discriminate between moderately and severely impaired patients initially after injury suggests that it may not classify patients with sufficient sensitivity for the purposes of research.

It has been found that the duration of PTA as measured by the Galveston Orientation and Amnesia Test (Levin, O'Donnell & Grossman, 1979) appears to be a significant predictor of functional outcome after TBI. Further, the duration of PTA can reflect the severity of the injury (Zafonte, Mann, Millis, Black, Wood & Hammond, 1997). The Galveston Orientation and Amnesia Scale (GOAT) is a short mental status examination. This test was devised to formally assess the extent and duration of confusion and amnesia following TBI. Eight of the 10 questions on the GOAT involve the assessment of the individual's orientation to time, place and person. The first event following the injury that the patient can remember and the last event that the patient can remember prior to the accident relate to anterograde and retrograde amnesia, respectively. In light of the relationship between the early return of the individual's orientation following TBI and a good outcome – as well as it's converse – the GOAT can also serve as a predictor of eventual outcomes. Additionally, and contributing to it's construct validity, GOAT measurements of PTA show strong associations with the severity of the injury (Levin, O'Donnell & Grossman, 1979).

The Oxford Test (Artiola i Fortuny, Briggs, Newcomb, Ratcliff & Thomas, 1980) is another measure that has been used to assess the duration of PTA. This test involves the formal testing of memory; the individual's orientation to time and place; and the last memories prior to the accident and the first memories following the accident. This test also includes a questionnaire about personal demographics, including marital status, occupation etc. this provides an indication of the individual's orientation to person. A perfect score on the Oxford Test for three consecutive days has been taken as an indication that PTA has ended on the first day of the three consecutive days. This test, as well as GCS scores and the GOAT, can also function to identify deterioration in a patient's condition, which may possibly occur due to secondary brain damage.

The Oxford Test was used as a basis for the development of the Westmead PTA Scale (Shores, Marosszesky, Sandaman & Batchelor, 1986). This test provides a standardised set of procedures that tracks the individual's daily cognitive performance. This measure is sensitive to both improvements and deteriorations in the individual's level of consciousness. The first scale in the Westmead PTA Scale asks seven questions about age, date of birth, month, time of the day, day of the week, year and name of the place. These questions are taken as an indication of the individual's orientation. Similar to the Oxford Test, PTA as assessed by the Westmead PTA Scale is judged to have ended on the first of three consecutive days for which the patient obtains a perfect score. The duration of PTA on this measure has been found to be a significant predictor of severe TBI outcomes.

This is not an exhaustive list of all the tests and measures that are used to assess TBI severity and indeed, there are other measures that have been used to assess this. Other measures include the number of days that the individual takes to achieve a total GCS score of 15/15, as well as the number of days to achieve a GCS motor score of 6/6 (Greenwald, Burnett & Miller, 2003). Of course, these measures are only applicable in the absence of motor or physical deficits. The Abbreviated Head Injury Scale (Walder, Yeoman & Turnbull, 1995) score has also been used to assess the severity of the injury.

Deficits as a Result of Traumatic Brain Injury

In terms of deficits, Mild TBI is typically associated with some degree of transient altered mental status or level of consciousness. These changes may include confusion and a lowered GCS score, or PTA. It has been contested in the literature whether the duration of PTA or the length of time of LOC can consistently predict symptoms and deficits after mild TBI. Complicating the possibility of prediction in

this regard is the fact that the timing of when the GCS score is determined varies considerably after an accident. The GCS score may be determined at the scene of the accident or only on admission to hospital. This may represent a substantial time delay post-injury. Additionally, one GCS score is not sufficient to assess the severity of the TBI. It is commonly the case that numerous GCS scores are recorded. Amnesia scale scores may also be recorded (Jagoda & Riggio, 2005).

Patients with mild TBI's are usually expected to make a complete recovery within several weeks to several months after their injury, especially if there are no complications, including secondary brain injury. Alexander (1995) estimates that only 15% of patients that have suffered a mild TBI evidence disability at 1 year post-injury. "The cognitive deficits caused by neurologic injury can be understood as manifestations of impaired attention" (Alexander, 1995, p. 1253). Thus, the cognitive difficulties that may be present after a mild TBI are considered to be secondary to attentional difficulties.

In comparison to mild TBI, both moderate and severe TBI are commonly associated with long-lasting, and often severe, neurological and cognitive impairment (Brooks, Hosie, Bond, Jennet & Aughton, 1986; Levin, Grossman, Rose & Teasdale, 1979). There are several cognitive sequelae that commonly manifest after moderate and severe TBI. These cognitive sequelae involve memory, attention and executive functions. It is important to note that these deficits are not certainties following moderate and severe TBI and that symptomatic dysfunction is a consequence of the region of damage in the brain, as well as the significance of the trauma and/or complications post-injury (Brooks et al., 1986).

As has previously been noted, memory deficits may be included in the major cognitive sequelae of moderate and severe TBI (Levin, 1989). Memory has been described as having three main divisions. The

first of which is sensory memory, which is only fleeting, lasting milliseconds, but it's capacity is essentially unlimited. The second division is short-term memory or working memory, which is of a limited capacity – 7± 2 'bits' of information – and degrades quickly over a matter of seconds if the information is not held by means of rehearsal or transferred to long-term memory (Miller, 1956). Working memory is further differentiated into the maintenance of information and the manipulation of information (Baddeley, 1986). The last division of memory is long-term memory (Atkinson & Shiffrin, 1967). Long-term memory is an unlimited capacity store that can hold information over lengthy periods of time. Of course, information can be lost from long-term memory (LTM) through forgetting (Zillmer & Spiers, 2001).

Long-term memory can be further divided into declarative memory and procedural memory. Declarative memory is explicit and accessible to one's conscious awareness. Under the umbrella of declarative memory falls episodic memory, which refers to memories for particular episodes, usually autobiographical in nature, that have specific spatial and temporal tags. Also falling under the umbrella of declarative memory is semantic memory, which refers to memory for information and facts that do not have a specific time tag reference. In contrast to this, procedural memory is usually implicit – a person may demonstrate procedural memory via the performance of activities (Zillmer & Spiers, 2001).

Long-term memory tends to be relatively well preserved in TBI (Azouvi, Jokie, van der Linden, Marlier, & Bussel, 1996). Nonetheless, long-term memory is not immune to the effect of TBI and it can be affected. If this is the case, this is referred to as retrograde amnesia; that is, memory for events prior to the injury may be inaccessible. If present at all, retrograde amnesia tends to involve a few minutes, hours, or more rarely days, immediately preceding the accident (Brooks, 1989, as cited in Lezak, 1995).

It has been documented that the extent of retrograde amnesia may shrink with time; however, most people with retrograde amnesia suffer a permanent loss of memory for some period of time prior to the accident. Patients with head trauma almost never recall the accident itself. The duration of retrograde amnesia also tends to correlate, at least to some degree, with the severity of the injury (Lezak, 1995).

In addition to deficits of memory functioning after moderate and severe TBI, attention deficits are also common (van Zomeren & Brouwer, 1994). The term attention can refer to a general level of alertness or vigilance; a general state of arousal; orientation versus habituation to a stimulus; the ability to focus, divide or sustain mental effort; the ability to target processing within a specific sensory arena; or a measure of capacity (James, 1890). In the past it was contested whether the term 'attention' implied a general state of cortical tone, or whether it referred to a set of specific structures or networks within the brain. Current views of attention hold that it is a multifaceted concept that implies multiple behavioural states and cortical processes that various anatomical structures control (Zillmer & Spiers, 2001).

Under the umbrella term of attention, there are several divisions or characterisations. The first of which is focused attention, which refers to the ability to respond to and pick out salient information from the background of irrelevant external and internal stimulation. Focused attention also implies a measure of concentration or effortful processing (Cherry, 1953). The second division is alternating attention, which refers to the ability to alternate attention or switch back and forth – often rapidly – between different tasks. The third division is known as divided attention and this term refers to the ability to partial out attentional resources concurrently, rather than switching rapidly back and forth quickly. The fourth division is sustained attention, which is the ability to maintain an effortful response over time; this is related to the ability to persist and sustain a level of vigilance (Sohlberg & Mateer, 1989).

Diffuse white matter lesions are commonly the result of diffuse axonal injury, which is the indirect or acceleration-deceleration mechanism of primary head injury. These diffuse lesions are responsible for the slowed speed of processing of information, as well as for reducing the available attentional resources (Azouvi, Couillet, Leclercq, Martin, Asloun & Rousseaux, 2004; Ponsford & Kinsella, 1992). As a result of the slowed speed of information processing that results from the many microscopic sites of diffusely distributed damage, activities that were previously automatic – or even semi-automatic – are often only accomplished with a concerted effort. Tasks and activities that are performed frequently during the day may become effortful. These activities may include concentrating, the warding off distractions, the monitoring of ongoing performances, and the planning activities. To further compound matters, as the individuals that have suffered diffuse axonal injury become fatigued, their efficiency levels plummet. Consequently, activities that were difficult when these individuals were rested become extremely laboured and more prone to errors (Ponsford & Kinsella, 1992).

A further point to note is that available attention resources are also often reduced in diffuse axonal injury. Subtle difficulties with attention may be present even in the case of less severe concussive brain injuries, for example in whiplash-type injuries. In these instances, cognitive deficits are present, but are often overlooked. These attentional difficulties and subtle cognitive deficits come to the fore when formal neuropsychological assessments are conducted (Ponsford & Kinsella, 1992).

In addition to memory and attention deficits following moderate and severe TBI, executive functions are often affected. Dysexecutive difficulties comprise both behavioural and attentional constituents. These dysexecutive difficulties are characterised by an individual's inability to formulate plans and to

undertake organised activities. Thus, executive dysfunction becomes most evident in the most complex of human conscious cognitive activity: this refers to those activities of higher problem solving, reasoning, abstraction, critical self-awareness and social interaction (Zillmer & Spiers, 2001). These types of deficits cause many functional difficulties in the course of daily life. Unfortunately, modifications in the individual's behaviour are common and may cause a significant burden to the family. The individual may become dysinhibited following moderate or severe TBI or, conversely, the individual may lose initiative and seem indifferent to activities of daily life and to the future (apragmatism). These types of difficulties have been reported to occur in 50 – 70% of severe TBI and can have variable severity (Cazalis, Azouvi, Sirigu, Agar & Burnod, 2001; Mazaux, Masson, Levin, Alaoui, Maurette & Barat, 1997).

Post-Concussion Syndrome following Traumatic Brain Injury

The post-concussion syndrome further complicates matters after TBI. Post-concussion syndrome (PCS) refers to a symptom complex experienced by many patients after TBI, regardless of the severity of the injury. Post-concussion syndrome is multi-dimensional and comprises cognitive, somatic and affective symptoms. The PCS cognitive symptoms include attention, concentration and memory problems (Jagoda & Riggio, 2005). Compounding this picture, both somatic and affective manifestations are known to impact negatively on optimal cognitive functioning (Brooks et al., 1986). The PCS somatic symptoms include fatigue and sleep disturbance, headaches, vertigo, dizziness, nausea, photophobia and hyperacusis. The PCS affective symptoms include irritability, anxiety, depression and emotional lability. Indeed, mood disorders, such as depression and anxiety, are common in individuals that have suffered moderate and severe TBI (Jagoda & Riggio, 2005). Major depression is diagnosed in approximately 40% of patients that have been hospitalised in either primary or rehabilitative hospitals for TBI (Jorge &

Starkstein, 2005). These affective manifestations may correspond to psychological reactions to the traumatic event precipitating the injury, to organic brain damage, including frontal lobe damage, or to a combination of the two (Belmont et al., 2006).

Thirty – 80% of TBI patients report suffering from PCS symptoms at three months post-injury (Jagoda & Riggio, 2005). Approximately 15% of patients report that PCS symptoms persist one year after the injury. It is thought that both organic and psychological factors contribute to the onset and the persistence of PCS (Wang, Chan & Deng, 2006). The literature is somewhat conflicting in terms of how long after a head injury recovery can still be expected to take place. The consensus seems to be that most improvement after a head injury occurs within the first year, but that recovery can still occur up to two years or even longer post-injury. After this time, it is considered that little significant spontaneous recovery is occurring (Levin, Eisenberg & Benton, 1989). Kraus, Schaffer, Ayers, Stenehjem, Haikang and Afifi (2005) found that approximately 83% of TBI patients reported suffering at least one PCS somatic symptom at their six-month follow-up.

Persistent Post-Concussion Syndrome following Traumatic Brain Injury

Persistent post-concussion syndrome (PPCS) refers to the symptom complex where patients continue to experience the same symptoms that are present in the acute phase of PCS. These symptoms may include dizziness; headaches; sensitivity to sensory stimuli, such as photophobia and hyperacusis; and so forth. The cognitive symptoms of PPCS are various manifestations of impaired attention, reduced memory and executive dysfunction. Emotional symptoms may also be prominent. The emotional symptoms include irritability, depression, nervousness, discouragement and anger. It is often the case that both the patient and some professionals attribute emotional symptoms to neurologic problems (Alexander, 1995).

Experiencing symptoms of PCS at one year post-injury indicates the diagnosis of PPCS should be made. Approximately 10 – 15% of patients suffering from PCS develop PPCS. There are some factors that can be used to make predictions regarding when an individual may develop PPCS out of PCS, including being of the female sex, ongoing litigation, a high level of pre-existing emotional stress, low socio-economic status, prior TBI's, headaches and associated systemic injury. Thus, both psychological factors, including depression and somatic factors, including headaches, have been noted to play a role in the evolution of PPCS (Alexander, 1995). Two studies have pointed to the causative role that chronic pain and depression play in the development of PPCS (Alexander, 1992; Ettlin, Kischka, Reichman, Radii, Heim, Wengen, et al., 1992). Chronic pain, particularly headaches, is noted to be a nearly universal component of PPCS (Alexander, 1995).

Rehabilitation after Traumatic Brain Injury

Rehabilitation therapists are often reluctant to continue working with patients when they see no more gains. When a person's recovery plateaus, usually within two years post-injury, formal rehabilitation efforts most often come to an end. It is important to note that even after the brain has stopped healing, significant environmental events, such as the death of a parent or spouse or the establishment of a new relationship, have been known to lead to sudden increases or decreases in the functional abilities of TBI patients (Kay & Lezak, 1990).

In the past, it was common practice for rehabilitation experts to wait until the natural healing process had finished prior to the initiation of rehabilitation. That is, rehabilitation experts waited approximately two years before initiating rehabilitation attempts. More recent thinking has proven that rehabilitation is most

effective when it is commenced as early as is medically possible (Levin, Eisenberg & Benton, 1989). Having said this, patients need to be out of PTA in order to benefit significantly from rehabilitation, particularly cognitive rehabilitation. If they are still in PTA, they will not be able to lay down new memories and in turn, they will have no memories of previous sessions. Furthermore, assessments done during this time will not be reliable or valid due to the significant confusion evidenced by patients in PTA. At times like this, it is important for the neuropsychologist merely to monitor changes in their cognitive status (Zillmer & Spiers, 2001) and to begin cognitive rehabilitation when the patients emerge from PTA.

The focus of rehabilitation hospitals has broadened to some degree over time. In the past, the focus was merely on physical rehabilitation and on training the patient to cope with the basic activities of daily living (ADL's), including toileting, feeding and dressing. There is now an increasing emphasis on addressing not only the physical deficits, but also the cognitive and behavioural difficulties of the patients (Kay & Lezak, 1990). This changing emphasis has accompanied the recognition of the far-reaching implications of deficits in these areas of functioning for the patient and for those around them.

Once formal rehabilitative efforts have come to an end, usually within two years post-injury, the typical patient will be ready to attempt to return to their former lives. Success in this regard is a complex issue, which depends on a number of factors. Cognitive difficulties; somatic difficulties, including fatigue; psychosocial difficulties and affective difficulties often preclude the successful return to either work or to school and it is unfortunately the reality that there are significant numbers of persons with TBI who fail to resume productive lives. Consequently, these people are often dependent on others for their livelihood for the remainder of their lives (Kay & Lezak, 1990).

Post-Concussion Syndrome in Individuals with and without TBI

It is pertinent to note that symptoms of PCS are not necessarily specific to brain injured patients; these symptoms can occur in people that do not have a history of TBI, or medical or psychiatric problems. It has been found that people with no history of a head injury endorse relatively high base rates of PCS symptoms. The symptoms that are commonly endorsed include fatigue, poor concentration, dysexecutive problems and forgetfulness (Chan, 2001). It is thought that people with no history of TBI may suffer from PCS complaints due to a variety of personal and psychological issues. These issues include study, work, stress and emotional state in everyday life (Wang, Chan & Deng, 2006). Based on these findings, it would be unwise to merely assume that these self-reported, non-specific symptoms are causally related to brain injury without critical assessment of the complaints (Iverson & Lange, 2003).

The fact that the prevalence of PCS symptoms in persons without TBI is high should be borne in mind by clinicians when considering a diagnosis of PCS in TBI patients. Furthermore, the assumption that self-reports of these symptoms are substantial evidence of neuropsychological impairment in patients with TBI for medico-legal cases should be questioned. Instead, it may be more useful for clinicians to utilise the degree or severity of PCS symptoms for guiding compensation claims (Wang, Chan & Deng, 2006).

A study that compared healthy individuals that report high levels of PCS symptoms and a sample of TBI patients with PCS revealed that the patients performed significantly worse on measures of neuropsychological functions than the healthy, high symptom reporters. This was despite the fact that differences in symptom endorsement between these two groups were non-significant. Research

conducted by Wang, Chan and Deng (2006) demonstrated that the base rate of PCS symptoms in a group of healthy university students was relatively high and that PCS symptoms were not related to neuropsychological functions in normal people. That is, there was no difference in the performance of healthy people with PCS and those without PCS on neuropsychological measures. It can be inferred from this study that it is not the PCS symptoms, but the brain injury itself, that results in the cognitive impairments in TBI patients.

Bohnen, Jolles and Twijnstra (1992) conducted a study that revealed inconsistent associations between the degree of cognitive impairment and the reporting of symptoms of PCS in TBI patients. Additionally, Wang, Chan and Deng (2006) found no significant differences in neuropsychological performance between TBI high PCS symptom reporters and TBI low PCS symptom reporters. This means that the patients with TBI who reported suffering from PCS symptoms did not perform significantly worse in any domain of cognitive functioning than the low PCS symptom reporters. The most notable difference between these two groups was in the subjective complaints of dysexecutive-like behaviour in everyday life.

In contrast to these findings, other empirical studies of brain injured patients with PCS have shown that these patients do indeed perform more poorly on neuropsychological tests than do TBI patients without PCS. Thus, patients with PCS may have more cognitive impairments than the latter group (Bohnen, Wijnen, Twijnstra, van Zutphen & Jolles, 1995). Gronwall and Wrightson (1974) found that cognitive efficiency was reduced on some of the neuropsychological measures used. Particularly, the authors found that efficiency was reduced on the Paced Auditory Serial Attention Test (Gronwall, 1977). These

findings were present in ten patients with head trauma and subjective PCS, but not in the patient group with head injury to the same degree but without the subjective syndrome.

Fatigue

Definition of Fatigue

Fatigue is the term that refers to the state whereby there is a conscious, decreased ability for physical and/or mental activity. This state may be due to several factors, including an imbalance in the availability, utilisation or retrieval of the physiological and/or psychological resources that are required to perform the specific activity (Aaronson, Teel, Cassmeyer, Neuberger, Pallikkathayil & Pierce, 1999). Normal fatigue refers to a "feeling of weariness related to effort, to the excess of physical or intellectual exertion" (Belmont et al., 2006, p. 371). Fatigue is a subjective phenomenon, which can manifest or be expressed in numerous ways; such as a lack of energy or motivation, weakness, fatigability, sleepiness, weariness, lassitude, boredom, adynamia, anhedonia (inability to experience pleasure) or abulia (organic depression after TBI). This subjectively experienced state is also associated with increasing resistance to further effort, increasing propensity towards less analytic information processing, as well as changes in mood (Meijman, 2000). Pathological fatigue refers to instances were one is subjectively fatigued despite the fact that no effort has been exerted. Pathological fatigue is excessive and typically does not disappear after rest or relaxation (Belmont et al., 2006). Fatigue is a complex and subjective phenomenon. Smets, Garssen and Bonke (1995) have proposed that fatigue is composed of at least three dimensions: general, physical and mental fatigue. Thus, the authors note that it's origins are multifactorial. Fatigue is an extremely frequent experience, and a universal phenomenon, that cannot be measured objectively.

Physical fatigue that occurs after sustained activity is physiologically observable, such as at the muscular level. Fatigue, then, may be thought of as a protective function of the body in order to avoid the harmful consequences of excessive effort, including decreased muscular strength and increased mistakes (Belmont et al., 2006). Mental fatigue is a change in one's subjective psychophysiological state due to the sustaining of performance. Sustained performance may not necessarily refer to or involve the same cognitive task, but can extend over several different tasks that all require the expenditure of mental effort (Desmond & Hancock, 2001). In participants that do not have a history of a brain injury, fatigue may occur following extended physical or muscular effort, as well as after sustained attention and inappropriate rest. Psychological fatigue refers to the state of decreased motivation, extended mental activity or boredom. Psychological fatigue often occurs in situations of effort or chronic depression (Lee, Hicks & Nino-Murcia, 1991).

It is pertinent to note that fatigue may appear in many different conditions. Fatigue may be present in conditions of infection, inflammation, endocrine and metabolic abnormalities, sleep disturbances, cancer, depression and neurological conditions (Belmont et al., 2006). That is, fatigue can occur as a result of the excessive consumption of energy, depleted hormones and/or the diminished ability of muscle cells to contract. Infection, and some other physiological conditions, may deplete the reserves of energy by creating an unrelenting physical demand for energy expenditure. In these cases, clinical intervention is usually related to the resolution of the physiological problem.

Fatigue after Traumatic Brain Injury

Fatigue is an important somatic symptom of PCS following TBI. Fatigue is an extremely common and frequently disabling symptom in patients with TBI, regardless of severity. It is reportedly present in 43 –

73% of patients in primary care internationally (Olver, Ponsford & Curran, 1996; van der Naalt, van Zomeren, Sluiter & Minderhoud, 1999). Unfortunately, fatigue remains in a vast majority of TBI patients five years post-injury. This statement is based on the fact that fatigue and mental effort have been found to be poorly correlated with time since injury (Olver, Ponsford & Curran, 1996) or to the severity of the injury (Belmont et al., 2006). In other words, fatigue and a reduction in stamina are common symptoms after a TBI and this often represents a permanent alteration in the patient's functioning. Furthermore, even though formal rehabilitation efforts aim to help many areas of functioning, fatigue often persists. Fatigue is assumed to remain due to organic factors and/or psychogenic factors. An organic factor contributing to the persistence of fatigue is neuronal damage that causes cognitive difficulties. The psychogenic factors contributing to the persistence of fatigue may include the emotional stress caused by the persistence of symptoms, as well as the psychological reaction to those symptoms (Rutherford, Merret & McDonald, 1979). Given the vast literature documenting the persistence of fatigue after TBI, this should be a factor considered in research of this population, especially in terms of its impact on cognitive functioning.

Several studies have reported that fatigue is one of the most disabling symptoms following TBI, regardless of the severity of the head injury (Dikmen, Machamer, Temkin & McLean, 1990; Ponsford, Olver & Curran, 1995; van Zomeren & van den Burg, 1985). Fatigue may be perceived by TBI patients to be abnormal, unusual or excessive. These patients have noted that is has an insidious onset, that it is persistent over time, and that it is not relieved by the usual restorative techniques, including rest and relaxation. Fatigue is noted to be substantially disabling because it has a major effect on the individual's abilities to complete the activities of daily living. Fatigue is also noted to affect TBI patients' quality of life. Furthermore, it reduces the efficacy with which these individuals can complete tasks – it has serious

functional consequences. Additionally, fatigue has serious emotional implications and consequences. People who suffer from excessive, chronic fatigue may experience subjective feelings of distress, and these individuals often become depressed or anxious as an emotional reaction to their physiological state (Aaronson et al., 1999).

Implications and Effects of Fatigue

Fatigue after TBI of any severity may be functionally constraining in daily life. It may also interfere with rehabilitation intervention attempts. Rehabilitation processes address, among other things, the cognitive disorders evidenced by the patients (Kay & Lezak, 1990). It has been found that patients who are suffering from fatigue do not benefit to the same extent from cognitive therapy as do the patients that are not fatigued or drowsy, but are more efficient. Complicating matters, when TBI patients are in primary care or when they are undergoing rehabilitation efforts, they are often heavily reliant on multiple medications. The TBI patients may be taking antidepressants, anticonvulsants (anti-epileptics), sedatives and sleeping tablets, to name but a few. Unfortunately, this contributes substantially to the fatigue that is experienced by patients, as the side-effects of many medications may make patients drowsy and tired. This will often negatively impact on the efficacy of rehabilitation attempts, including cognitive rehabilitation. Fatigue is an important indicator of illness and/or the likely responsiveness of patients to medical and rehabilitation interventions (Lee, Hicks & Nino-Murcia, 1991). Successful rehabilitation depends on the patients being in the correct frame of mind to be able to benefit from the intervention attempts.

Furthermore, fatigue is a burden on the return of TBI patients to their former lives, including work or school. Fatigue reduces the ease and efficiency with which patients can attempt to return to work or to

school. These individuals often need to make substantially more of an effort to function at their pre-injury level, which in turn will tend to further fatigue these individuals (Lee, Hicks & Nino-Murcia, 1991).

Fatigue has implications for safety, particularly in the work setting (Yoshitake, 1978); fatigued individuals tend to make more errors than do non-fatigued persons. In industry, many incidents and accidents have been related to mental and physical fatigue as a result of sustained performance. Undoubtedly, this applies to both organically compromised and uncompromised individuals; that is, those with TBI and those without. However, the TBI individuals are less likely to be able to compensate for their errors than the individuals with no history of a head injury (Baker, Olsen & Morrisseau, 1994).

Due to the many challenges it creates, fatigue poses a substantial economic burden. It has been estimated that the economic burden of TBI in the United States was approximately $37.8 billion in 1985 and is substantially more now. This estimate included $4.5 billion in direct expenditures for hospital care, extended care and other medical care and services; $20.6 billion in injury-related work-related losses and disability; and $12.7 billion in lost income from premature death (Max, MacKenzie & Rice, 1991). There is a substantial loss of income in the workplace globally due to the inefficient work and increased errors as a result of fatigue, as well as other cognitive difficulties.

Many studies have reported the complaint of fatigue after TBI; however, few studies in this regard have investigated either the mechanisms or the implications of fatigue (Belmont et al., 2006). According to Riese, Hoedemacker, Brouwer, Mulder, Cremer and Veldman (1999), mental fatigue is expressed in patients by different subjective complaints, such as fatigability during the performance of cognitive

tasks, irritability, and/ or the increased frequency of headaches. These complaints are reported, often even in the absence of affective dysfunction, which can result in fatigue, regardless of the severity of the head injury.

Ziino and Ponsford (2005) conducted a study to investigate the causes and impact of fatigue after a head injury. A sample of 49 healthy controls and 49 patients of variable TBI severity were examined approximately 8 months after TBI. Compared to the control participants, the TBI patients reported a higher, more substantial impact of fatigue on functioning. It was noted that the activities requiring physical and/or mental effort were frequent causes of fatigue. The authors found that the severity of the TBI, gender and age were not significant predictors of experiencing fatigue. Thus, fatigue was reportedly not more common after severe than mild TBI. Additionally, the subjective experience of fatigue does not seem to differ between men and women after TBI.

van Zomeren, Brouwer and Deelman (1984) proposed the Coping Hypothesis to explain the affects fatigue after TBI, whereby fatigue is posited to be secondary to impairments of cognitive functioning. Fatigue, in this regard, is due to the constant effort that TBI individuals need to exert to meet the demands of daily life, as well as to compensate for the slowed speed of information processing and the attentional impairments that result from brain injury and subsequent neuronal damage or death. Based on the coping hypothesis, in order to perform a cognitive task one would require a high degree of mental effort, which could lead to a subjective sensation of fatigue. Riese et al. (1999) experimentally studied the coping hypothesis. The authors studied the effects of fatigue and psychophysiological stress in 8 severe TBI patients and control participants during a 50 minute, divided attention task. The patients' neuropsychological performance did not decrease more than the healthy control participants did over

time. However, the authors found that blood pressure increased in the patients, but decreased in the control participants. The authors felt that this result was suggestive that there was an increased psychophysiological cost for TBI patients compared to controls.

Ziino and Ponsford (2005) recently studied the relationship between fatigue and deficits in attention in a sample of 46 patients of various TBI severities. They assessed fatigue through the use of a subjective fatigue scale. They utilised several physiological measures, including blood pressure. In this study, the TBI patients had to perform a long-duration (45 minutes), complex visual selective attention task. It was found that patients had higher levels of subjective fatigue than did controls. The patients also had higher levels of physiological fatigue, as measured by increased diastolic blood pressure, than did controls. High subjective fatigue scores were found to be correlated with a higher number of mistakes on the attention task, which suggests that post-TBI subjective fatigue could be related to a high effort required to maintain a good performance level over time. This effort would have a psychophysiological cost, which would plausibly be expressed as a subjective sensation of fatigue.

In a sample of 43 patients with severe TBI, Azouvi et al. (2004) assessed the relationship between the impairment of attention and mental effort. The results of their research suggested that the attention deficits that were evident in the TBI patients were related to a decrease in the availability of attentional resources. The patients in this study reported high levels of subjective mental effort. This result is likely generalisable and could serve to explain why TBI patients frequently complain of mental fatigue.

The Assessment of Fatigue

It is difficult to assess levels of fatigue with objective tests. For this reason, most assessment scales of fatigue rely on subjective self-reports. In the past, five scales have been predominantly used to evaluate fatigue in TBI patients. These tests include the Fatigue Severity Scale, the Visual Analogue Scale for Fatigue, the Fatigue Impact Scale, the Barrow Neurological Institute Fatigue Scale and the Cause of Fatigue Questionnaire (Belmont et al., 2006).

Krupp, LaRocca, Muir-Nash and Steinberg (1989) developed the Fatigue Severity Scale (FSS). The FSS is a nine-item scale that serves to assess levels of physical fatigue, the consequences of fatigue on the psychosocial environment and fatigue in general. This self-report questionnaire requires that patients rate their responses on a scale from 1 (strongly agree) to 7 (strongly disagree). An advantage of the FSS is that it gives an indication of the degree to which fatigue impacts on an individual's functioning. Furthermore, the sensitivity of the FSS has been demonstrated in previous research. However, the emphasis of this scale is placed on physical fatigue, and not cognitive fatigue. Additionally, the items on this scale are "not necessarily relevant or specific enough to the experiences of patients" with severe TBI (Borgaro, Gierok, Caples & Kwasnica, 2004, p. 686).

The Fatigue Impact Scale (FIS) is a 40-item questionnaire that assesses fatigue in several dimensions, including cognitive, physical and social dimensions. The FIS requires that patients rate their responses on a scale from 0 (no problem) to 4 (extreme problem). This measure has been shown to have good internal consistency, but it is a relatively longer test to administer than the FSS (Fisk, Pontefract, Ritvo, Archibald & Murray, 1994a; Fisk, Ritvo, Ross, Haase, Marrie & Schlech, 1994b). Furthermore, the structure of the FSS is not conducive for assessing levels of fatigue in severe TBI patients, as it would

likely “exceed the level of cognitive and mental endurance often displayed by these patients” (Borgaro et al., 2004, p. 686).

The Barrow Neurological Institute (Borgaro et al., 2004) fatigue scale questionnaire makes up for what the FIS lacks in that this measure was specifically designed for brain-injured patients. The Barrow Neurological Institute (BNI) comprises 10 items, each of which is assessed on a scale from 0 (rare problem) to 7 (problem present most of the time). In addition to this, the BNI includes an overall scale from 0 to 10, to score the global level of fatigue. The BNI is brief to administer and requires only five minutes to complete, even in TBI populations. Borgaro et al. (2004) found that items frequently reported by TBI patients on the BNI were difficulty to perform complex tasks without tiredness; difficulty to hold attention during an entire activity; difficulty to not go back to sleep during the daytime; as well as difficulty not to take a nap during the daytime.

In a similar vein to the BNI, the Cause of Fatigue (Ziino & Ponsford, 2005) questionnaire was specifically designed for individuals that have sustained TBI. The Cause of Fatigue (COF) questionnaire includes twelve activities that are potentially responsible for fatigue. These activities include six mental tasks, four physical tasks and two mixed (mental and physical) tasks. Thus, the emphasis of the COF is not solely on cognitive fatigue, but is also on physical fatigue.

Instantaneous fatigue is assessed by the Visual Analogue Scale for Fatigue (Lee, Hicks & Nino-Murcia, 1991). The Visual Analogue Scale for Fatigue (VAS-F) comprises 18 items: 13 of which measure the intensity of fatigue and 5 of which measure the intensity of energy. As opposed to one-item measures, the VAS-F is a more stable estimate of fatigue, which is a subjective phenomenon. The VAS-F has

simple administration instructions, is completed with minimal time and effort, and it is easy to score. An advantage of this test is that the lines used do not restrict participants to arbitrary intervals. With the VAS-F, data are obtained as continuous intervals and thus, the assumptions for parametric statistical analyses, such as normal distribution of data points, are met (Aitken, 1969). Thus, the VAS-F results do not require transformations in order to be statistically manipulated. Lee, Hicks and Nino-Murcia (1991) consider it to be valid and reliable in both non-pathologic populations and pathologic populations. A significant positive correlation has been found between the FIS and the 13 fatigue items of the VAS-F, as well as a significant negative correlation between the five energy items of the VAS-F and the other scales (LaChapelle & Finlayson, 1998).

Belmont et al. (2006) have proposed that the assessment of cognitive fatigue cost, or fatigability, be considered. Fatigability refers to the increase in levels of fatigue during the completion of a task. Fifteen patients with severe TBI were included in the sample of this study and were required to score their fatigue on the VAS-F before, during and after a long-duration (60-minute), selective attention task. The results showed that the patients' baseline levels of fatigue (before the task) were higher than that of control participants. However, subjective fatigue increased in a parallel way in both patients and controls during the completion of the long-duration, cognitive task. Additionally, the reported levels of fatigue in patients did not increase significantly more than that of the controls at the end of the task. It was inferred from this study that cognitive impairment was not significantly correlated with fatigability (Belmont, 2004, as cited in Belmont, Agar, Hugeron, Gallais & Azouvi, 2006).

Factors contributing to Fatigue after Traumatic Brain Injury

It is important to note that there are many factors that may contribute to the onset and persistence of fatigue in patients that have suffered TBI. Sleep disorders are present in 50 – 73% of patients after TBI and are undoubtedly a cause of fatigue (Castriotta & Lai, 2001; Cohen, Oksenberg, Snir, Stern & Groswasser, 1992). However, some patients who are tired do not have sleep disorders and it is not necessarily the case that all patients with sleep disorders suffer from fatigue. Clinchot, Bogner, Mysiw, Fugate and Corrigan (1998) reported that 50% of patients with TBI had sleep disorders and that 63% of the TBI patients were tired. The authors go on to report that among the 50% of patients with sleep disorders, 80% complained of fatigue.

Research into the relationship between fatigue and depression is lacking. Previous studies have reported inconsistent rates of prevalence of depression after TBI (6 – 77%). In a study of 666 TBI patients at approximately 3 years post-injury, Seel, Kreutzer, Rosenthal, Hammond, Corrigan and Black (2003) found that 29% of patients who had been diagnosed with depression complained of fatigue. Indeed, fatigue is frequent among people with emotional disorders (Solberg, 1984). Kreutzer, Seel and Gourley (2001) found that 42% of patients with TBI were depressed. Of these depressed TBI patient, 46% complained of suffering from fatigue. Ziino and Ponsford (2005) report that the relationship between fatigue and depression after brain injury is complex. The authors also found moderate to strong correlations between depression and the VAS-F fatigue items. According to the COF scale, depression was related to mental effort as the main cause of fatigue. However, depression was not significantly correlated with the impact of fatigue on daily-life or with physical effort as the primary cause of fatigue. Depression has been fond to disrupt cognitive operations. Depression particularly affects concentration,

memory and executive functions. Compared to TBI patients who are not depressed, depressed TBI patients often evidence much more limited cognitive functioning (Alexander, 1995).

Ziino and Ponsford (2005) conducted a study of the relationship between fatigue and emotional illness. The authors found a moderate to strong correlation between anxiety and levels of fatigue. Anxiety, irritability and other mood disorders are frequent in fatigued TBI patients. The reasons for these findings may include psychological factors, including emotional reactions to the event. As in the case of depression, anxiety disrupts concentration and complex mental operations. Another reason for these findings may be neuronal injury. Furthermore, TBI patients suffering from fatigue, even with no premorbid history of psychiatric disease, are much more likely to develop a clinical diagnosis of depression or anxiety (Alexander, 1995).

Endocrine disorders are frequent (35 – 51% pituitary insufficiency) following a TBI, but are unrecognised most of the time. This is as a result of the fact that post-TBI endocrine disorders are infraclinical and their manifestations are often unspecific. The endocrine disorders that have been found in TBI patients include a deficit of growth hormone, adrenal insufficiency, hypothyroidism, hypotestosteronism and hypoprolactinemia. These disorders are frequently associated with a reduction in strength, in aerobic ability and in well-being. The consequences of this are often problems with attention and memory, and depression, anxiety and/or fatigue (Popovic, 2005). van Zomeren, Brouwer and Deelman’s coping hypothesis (1984) is a very plausible explanation of post-TBI fatigue. Nevertheless, depression, anxiety, sleep disorders and endocrine dysfunction are other causative factors that should be taken into consideration when an individual presents with a complaint of fatigue.

Treatment of Fatigue after Traumatic Brain Injury

There are multiple approaches to the treatment of post-TBI fatigue, including pharmacology, rehabilitation and re-adaption. DeMarchi, Bansal, Hung, Wroblewski, Dua, Sockalingam et al. (2005) reviewed some pharmacological treatments that were used to stimulate TBI patients. The treatments they reviewed included psychostimulants, antidepressants and anticonvulsants (anti-epileptics). However, the results of their study failed to show significant evidence for the efficacy of any of these treatments. Thus, there is no known specific treatment for fatigue.

Fatigue and Executive Functioning

Compromised executive control evidenced in the completion of complex tasks, may become manifest as decreased mental flexibility. van der Linden, Frese and Meijman (2003) examined executive control in this respect through the use of the Wisconsin Card Sorting Test (Berg, 1948; Grant & Berg, 1948). This test measures flexibility in thinking, including perseverative errors. The authors showed that a sample of fatigued TBI patients displayed more perseveration on the Wisconsin Card Sorting Test (WCST) than did the non-fatigued group. The findings of their study indicate that executive control is compromised under fatigued conditions. This result may serve to explain the typical errors and sub-optimal performance that are often found in fatigued people.

Mental fatigue is often induced through working on cognitively demanding tasks for a considerable time, which can undoubtedly impact negatively on task performance. However, it is unclear how the cognitive control of behaviour changes under conditions of fatigue. Some researchers have proposed that mental fatigue affects only the cognitive control processes that are directly involved in the organisation of actions and that play a major role in deliberate and goal-directed behavior. This explanation is referred to

as the Control View of fatigue (Bartlett, 1943). The control view of fatigue has been supported by other relevant findings. The relevant research reports that performance on simple or well-learned tasks, which can be executed in a more or less automatic way, can be maintained over long periods of time, after sleep deprivation, or even after mentally demanding activities. In contrast to this, complex tasks that require the deliberate control of behaviour have been found to be generally difficult to perform under such fatigued conditions (Broadbent, 1979).These typical effects on information processing, and the specific disorganisation of behaviour that tends to occur under fatigue, both suggest that mental fatigue is mainly characterised by the deterioration of executive control. Executive control in this respect refers to the ability to regulate both perceptual and motor processes in order to respond in an adaptive way to novel or to changing task demands (Baddeley & Logie, 1999, as cited in van der Linden, Frese & Meijman, 2003).

It is through executive control that humans are able to "…couple almost any response to almost any stimulus, even when there are neither innate nor acquired connections between stimulus and response" (Goschke, 2000, p. 331). The literature is conflicting regarding the nature of executive control processes, for example whether executive control refers to the inhibition of irrelevant information (Fuster, 1989, as cited in van der Linden, Frese & Meijman, 2003), to task set maintenance, to task set switching (Engle, Kane & Tuholski, 1999), or to the updating of working memory (Miyake, Friedman, Emerson, Witzki, Howerter & Wagner, 2000). These processes have all been proposed as core aspects of executive control. On the other hand, several researchers have also proposed that all these processes have an "… underlying commonality" (Kimberg & Farah, 1993, p. 415). This indicates that there may be some more basic, underlying process responsible for the behavioural manifestations of control. In other words, it has been posited that the control of goal-directed behaviour depends on the ability to keep both goals and

goal-related information active in mind. Goals and goal-related information refer to all of the information regarding the conditions under which certain actions are executed. Some researchers have referred to this as the task context. Such information should be considered as a set of end-states and task rules, which when held in mind, can exert their influence directly on the selection of actions. This will result in the biasing of behaviour towards the attainment of goals (Kimberg & Farah, 1993).

In the case of compromised executive control, it is not the mental representation of the goal itself that is affected. Instead, it is the level of activation through which a goal can influence the selection of actions that is reduced (Kimberg & Farah, 1993). During these periods when goal-activation is reduced, actions tend to be guided more by automatic processes, which are triggered by situational or external cues. This takes place even when it is inappropriate. Duncan, Emslie, Williams, Johnson and Freer (1996) referred to such periods as goal-neglect. It is thought that goal-neglect may be underlying many of the problems of executive control. In general, Duncan et al. (1996, p. 258) argued that when executive control is compromised "…in different contexts the patient may appear perseverative or distractible, rigid or inappropriate, passive or impulsive and dysinhibited." It has also been argued that fatigued people display a tendency to reduced executive control and consequently, they show these types of deficits in task performance.

There are very few studies that have explicitly investigated the effects of mental fatigue from an executive control perspective (van der Linden, Frese & Meijman, 2003). However, one study specifically investigated the effects of fatigue on response planning and task switching, both of which are considered to be important aspects of executive control. Lorist, Klein, Nieuwenhuis, de Jong, Mulder and Meijman (2000) showed that with the increased time spent on cognitively demanding tasks, there was a reduced

involvement of those brain areas that are associated with the exertion of executive control, the frontal lobes. This result supported the authors' initial expectations regarding the effects of mental fatigue. In addition, fatigue led to an increased number of errors and increased reaction time. However, the study did not reveal differential effects of fatigue on switch and non-switch trials, neither did it show effects of fatigue on response planning. Thus, at a behavioural level a specific effect of mental fatigue and task switching, which is thought to be an element of executive control, was not found.

In a separate study that investigated the effects of mental fatigue from an executive control perspective, mental fatigue was induced through prolonged time spent on mentally demanding tasks. Participants were required to work through cognitive tasks that were different from the experimental task. This study utilised different cognitive tasks and not the same task repeatedly, so that the experimental task was novel. This was deemed to be important as executive control is particularly critical to behavior when the task is novel and participants have not been instructed what to do or have been given a chance to practice the task. It is more difficult to detect the effects of fatigue on cognitive processed in well-practiced participants (Duncan et al., 1996).

In the Duncan et al. (1996) study, the experimental cognitive task required that participants develop their own strategies and process feedback adequately. It was expected that fatigued people would show deficits in cognitive flexibility, which is considered to be a hallmark of executive control (Fuster, 1989, as cited in van der Linden, Frese & Meijman, 2003; Gazzinga, Ivry & Mangun, 1998). A deficit in mental flexibility often manifests itself in behaviour as a tendency to perseverate or to maintain an inefficient response strategy (Norman & Shallice, 1986, as cited in van der Linden, Frese & Meijman,

2003). In order to test whether fatigue leads to these specific changes in task performance, a task that has been used extensively in executive control research, the Wisconsin Card Sorting Test, was utilised.

The WCST provides a standardised measure of the ability to identify abstract categories and to shift cognitive response set. The WCST has been used in previous research to test whether fatigue does indeed coincide with increased perseveration, which would indicate compromised executive control (van der Linden, Frese & Meijman, 2003). Perseveration on the WCST refers to the instance where people tend to continue applying previous sorting rules that are no longer valid. In this particular study, it was found that fatigued participants did indeed display more perseveration on the WCST.

The Wisconsin Card Sorting Test: A Measure of Executive Functioning

In the Wisconsin Card Sorting Test (WCST), participants are required to discover the rules governing how cards that hold geometrical figures should be sorted. In this task, sorting rules are based on one of the following contingencies: the colour, the shape or the number of figures on each of the cards. However, because no detailed instructions are given regarding how the cards are to be sorted, participants must discover the sorting rules independently through systematic exploration. In the WCST, such exploration is supported or followed by feedback after each trial. Once participants have discovered the currently active sorting rule (which in the WCST is operationalised as ten correct consecutive responses), the rules by which the cards match change without notice. The participants are then required to use subsequent feedback to observe or notice that the sorting rule has changed and they must discover the new sorting rule (van der Linden, Frese & Meijman, 2003).

A study was conducted by Tsuchiya, Oki, Yahara and Fujieda (2005), which showed no significant differences in results for the variables age, gender, number of categories achieved, or number of errors on the WCST. Paolo, Troster, Axelrod and Koller (1995) contend that adults up until the age of 75 years perform similarly on this measure and achieve at least four category shifts. It can be inferred from this study that the effects of age are generally inconsequential on the WCST, up until the 70's (Boone, Miller, Lesser, Hill & D'Elia, 1990). The age-related effects that are evident on the WCST in individuals over 75 years have been attributed to impaired working memory and slowed speed of processing (Fristoe, Salthouse & Woodard, 1997). Previous research has demonstrated that education affects performance on the WCST only to a small degree. Gender has been shown to affect performance on the WCST, but this finding was not significant prior to the age of 45. Interestingly, a study by Boone, Ghaffarian, Lesser, Hill-Gutierrez and Berman (1993) showed that women over 45 years of age outperformed men on this task.

Many clinical studies of the WCST have demonstrated that the most common measures to assess executive control are the number of perseverative errors and the number of discovered sorting rules (Heaton, 1981; Milner, 1963; Norman & Shallice, 1986, as cited in van der Linden, Frese & Meijman, 2003). Kimberg and Farah (1993) used cognitive modeling to show that increased levels of perseveration on the WCST can be ascribed to decreased goal activation. In other words, when feedback about the invalidity or incorrectness of the current sorting rule is not held sufficiently active in mind or given sufficient attention, actions continue to be guided by previous sorting rules, which already have a high activation level. Milner (1963) has shown that as a result of perseveration and the use of inflexible strategies to search for sorting rules, sub-optimal executive control has also been associated with a low number of discovered sorting rules.

In addition to perseverative errors on the WCST, there are other types of non-perseverative errors that people make on this measure (Heaton, 1981; Milner, 1963). There are several underlying reasons that have been proposed to account for non-perseverative errors. These reasons include incorrect guessing when trying to discover the sorting rule, difficulties in holding the current sorting rule active in mind, and/or lapses in task set maintenance often due to a lapse in attention or concentration (Hartman, Bolton & Fehnle, 2001). Studies examining non-perseverative errors on the WCST have showed somewhat mixed results. Some studies report that compromised executive control did not only lead to perseverative errors, but that is also lead to non-perseverative errors. Paolo et al. (1995) reported that in the elderly, who typically show deficits on the WCST, perseverative and non-perseverative errors were positively correlated. The WCST has also been studied in fatigued populations. The results of these studies demonstrate that mental fatigue is most frequently associated with an increased number of perseverative errors (Heaton, 1981). In other words, mental fatigue is predominantly associated with increased perseveration and a lower number of card sorts.

Somsen, van der Molen, Jennings and van Beek (2000) have argued that the WCST consists of two qualitatively different types of problems and consequently, two different types of problem solving strategies must be utilised. The two types of problem solving strategies are rule application and rule search. Rule application means that once the sorting rule is discovered, participants must remember by which rule to sort. The participants need only perform relatively simple cognitive operations, such as matching the cards based on colour. On the other hand, when the current sorting rule is unknown, participants have to engage in rule search, which involves flexibly reacting to feedback and they need to conceptualise new task rules.

Several psychophysiological studies have been conducted that show that rule search places heavy demands on executive control processes, whereas rule application does not (Barcelo, Munoz-Cespedes, Pozo & Rubia, 2000). For this reason, the response times that participants show during rule search and rule application may provide additional insight into the processes underlying their behaviours on the task. Specifically, several studies have showed that response selection that is automatic takes less time than response selection that involves executive control. Thus, shortened response times during rule search and increased perseveration would support the inference that executive control is compromised during the conceptualisation of sorting rules. Conversely, prolonged response times and increased perseveration would indicate that despite executive control being exerted, it is ineffective in preventing inappropriate actions being taken (Monsell & Driver, 2000).

The Forward Digit Span Test: A Control Measure of the Effects of Fatigue on Executive Functioning

Compromised executive control under fatigue may imply that it is not all aspects of cognitive performance that are affected: only those aspects that involve cognitive flexibility and the deliberate regulation of actions are affected. The Forward Digit Span Task, which is not typically regarded as being complex, requires one to hold information in mind for a short period of time and to reproduce that information immediately after it has been presented. This is deemed not to rely heavily on executive control (Norman & Shallice, 1986, as cited in van der Linden, Frese & Meijman, 2003). Indeed, it has been argued that the Forward Digit Span is relatively insensitive to compromised executive control because it merely relies on the maintenance of information in short-term memory by means of rehearsal, which in most people is a well-learned skill (Norman & Shallice, 1986, as cited in van der Linden, Frese

& Meijman, 2003). Leading on from this, Kimberg and Farah (1993) have argued that simple memory tasks are not affected by compromised executive control, because these types of tasks do not involve different sub-sets of goals that may interfere with each other, as is the case in the WCST. When performance on the Forward Digit Span Task remains unaffected by the effects of mental fatigue, this indicates that the effects of fatigue on the WCST may not be ascribed to a simple inability to hold information in mind or to a general lack of compliance by fatigued participants.

Rationale

There are several reasons for conducting this research. There are only a few studies that have explicitly investigated the effects of mental fatigue from an executive control perspective (van der Linden, Frese & Meijman, 2003). Many studies have reported the complaint of fatigue after traumatic brain injury, regardless of severity. However, few studies have formally investigated the mechanisms and implications of fatigue on cognitive functioning (Belmont et al., 2006).

Fatigue after TBI of all severities is functionally constraining in daily life. Fatigue adversely impacts on the formal rehabilitation process. Furthermore, fatigue is an important indicator of the responsiveness of patients to medical intervention (Lee, Hicks & Nino-Murcia, 1991); fatigue negatively impacts on the efficacy of interventions, including neuropsychological rehabilitation. Thus, successful cognitive rehabilitation depends on the patients being in the correct frame of mind. Importantly, fatigue does not seem to be significantly related to the severity of injury or to the time that has elapsed since injury (Belmont et al., 2006). It is vital to understand fatigue in the context of rehabilitative interventions,

including neuropsychological rehabilitation, and it's impacts in this context. This understanding would lead to the increased efficacy of cognitive rehabilitative efforts.

Fatigue has been associated with placing restrictions on an uncompromised return to the workplace or to school in individuals with TBI. Fatigue is thought to affect work or school performance, learning and memory. Thus, fatigue affects everyday functioning and for this reason, the individual may need some form of compensated work, tailored work requirements and fewer demands and responsibilities, supervision and/or a structured programme to enable them to work efficiently.

In industry, many incidents and accidents have been related to mental fatigue as a result of sustained performance (Baker, Olsen & Morrisseau, 1994). This applies to both organically compromised and uncompromised individuals. Fatigue is a phenomenon that is of concern to health care practitioners because of the implications it holds for safety in the work setting (Yoskitake, 1978). Therefore, in order to deal with or prevent fatigue-related errors and accidents, it is important to understand the nature of mental fatigue and it's specific effects on cognition and behaviour. This study was conducted to provide additional insight into fatigue and it's underlying processes, particularly in organically compromised individuals.

Furthermore, because of the safety concerns in the workplace a tremendous amount of money and research is invested in work-safety, for example the use of co-drivers and the length of trips permitted for European articulated truck and bus drivers. It is imperative for companies to be assured that organically compromised individuals can be measured according to the same standard as non-organically compromised individuals; otherwise, they are putting people's lives in danger. If this is not the case and

these compromised individuals cannot be measured against the same standard, then this must be given special consideration in their compensation claim (Personal communication, 2007).

Fatigue also has implications for neuropsychological assessment. Fatigue may affect cognitive functions differentially; fatigue may impact executive functions to a different degree than other cognitive functions. Thus, fatigue may impact on the results of neuropsychological tests differentially. This needs to be borne in mind, particularly when neuropsychological evaluation is imperative to a medicolegal claim. Importantly, a fatigued state may more closely approximate an average day's functioning of the individual than a well-rested state. Fatigue when testing may give a more realistic picture of real-world functioning, which would result in a more accurate estimate of appropriate compensation. Nonetheless, neuropsychological testing while the patient is not fatigued, such as early in the morning, provides information about their functioning under optimal conditions. Under these conditions, standardised conclusions about their deficits can be reached and generalisations to other contexts can be made.

Fatigue also has significant mood implications; fatigue is generally found to affect mood. People suffering from fatigue may experience subjective feelings of distress, and often become depressed or anxious as an emotional reaction to their physiological state (Aaronson et al., 1999). Unfortunately, depression and anxiety, in turn, negatively impact on efficient cognitive functioning. This serves to further exacerbate the symptoms of fatigue due to the increased effort fatigued individuals need to make in order to function at their premorbid level.

Research Questions

1. Is mental fatigue associated with reduced cognitive flexibility, which is the inability to change response set when it is no longer appropriate, as operationalised by increased perseveration?
2. Is mental fatigue associated with reduced inductive reasoning, as operationalised by a lower number of card sorts?
3. Is mental fatigue associated with reduced conceptual abilities, as operationalised by increased non-perseverative errors?
4. Is mental fatigue associated with a decrease in attentional capacity or distractibility, as operationalised by an inability to maintain set?
5. Is the ability to hold information in mind, as operationalised by performance on a simple, short-term memory test, which is independent of executive control, free from the effects of mental fatigue?

Method

Research Aim

The present study was directed at an examination of the impact of fatigue on the executive control of behaviour in an organically compromised population. It was an attempt to answer the question as to whether fatigue, as measured by a subjective questionnaire, negatively impacts on executive control. Executive control, which refers to the ability to sustain attentional capacity as required to regulate perceptual and motor processes in order to facilitate the inductive reasoning required to respond in an adaptive way to changing task demands (Baddeley & Logie, 1999, as cited in van der Linden, Frese & Meijman, 2003), was operationalised as decreased cognitive flexibility and increased perseveration as measured by the Wisconsin Card Sorting Test.

Research Design

The researcher assessed the psychometric assessment data that was available within the practice of a clinical psychologist specialising in the evaluation, prognosis and treatment of individuals following traumatic brain injury. Assessment protocols that were considered in the analysis reflected moderate to severe closed head injury and, together with other measures, included both the selected measure of executive function and a measure of fatigue. The specific assessment schedules adhered to as part of the daily, ongoing work within this clinical practice were classified as representative of a fatigued or non-fatigued mental state at the time of administration of the relevant measure of executive function.

A group of TBI participants formed the first contrast group. Given that the analysis was based on the available data, there was no manipulation of an independent variable, nor was there any randomisation present. The data of the participants that met the inclusion criteria (as discussed under the heading 'Participants') was selected, and thus, purposive sampling was utilised. For this reason, this research design is a non-experimental, ex-post facto design. Non-experimental designs are used in cases where there is no manipulation of an independent variable and no randomisation of participants into control and experimental groups. Ex-post facto designs are used in situations where the data is already in existence and the independent variable is already in place or happening (Rosnow & Rosenthal, 1996).

No statement could be made regarding the relationship between fatigue and brain injury unless it was ascertained whether two hours of psychometric testing caused fatigue in both brain injured and non-brain injured populations with the same effects that have nothing to do with the brain injury at all. To meet this criterion of the investigation, a control group of volunteers that do not have a history of TBI were assigned to a fatigued group or to a non-fatigued group fatigued, thus, complying with a quasi-experimental research design. Quasi-experimental research designs are used in situations where there is no random assignment of participants to different conditions, but where the investigator manipulates or controls for the independent variable (Rosnow & Rosenthal, 1996).

A variable is the construct under investigation in research and must take on different values. An independent variable is the hypothesised or assumed cause. In this investigation the independent variable was fatigue, which is a between-subjects variable. A between-subjects variable is characteristically found when each sample of participants is exposed to a different level of the independent variable

(Rosnow & Rosenthal, 1996). In this investigation there was a second independent variable of TBI (or no TBI), which is also a between-subjects variable.

A dependent variable is the hypothesised or assumed effect; it is variable, the changes in which are viewed as being dependent on or due to changes in the independent variable (Rosnow & Rosenthal, 1996). The dependent variables were the different aspects of performance on the WCST. The first dependent variable examined was cognitive flexibility, which is the inability to change response set when it is no longer appropriate. This was operationalised as increased perseveration on the WCST. The second dependent variable that was examined was attentional capacity or distractibility, which was operationalised as an inability to maintain a response set on the WCST. The third dependent variable that was examined was inductive reasoning, which was operationalised as the number of card sorts on the WCST. The fourth dependent variable that was examined was conceptual abilities, which was operationalised as the non-perseverative errors on the WCST. The fifth dependent variable that was examined was the ability to hold information in mind, as operationalised by performance on a simple, short-term memory test, the Forward Digit Span Test.

Participants

In terms of inclusion criteria, participants in both the TBI and non-TBI groups were all Caucasian, English-speaking individuals in order to eradicate the possible effects of socio-cultural factors on results. All participants had at least twelve years of formal education at either secondary or tertiary level. All participants were right handed, so as to exclude the possible confounder of differing hemispheric dominance. Participants were matched as far as possible in terms of age. This was deemed important

because elderly people, over approximately 75 years of age, evidence reduced performance on tests of cognitive functioning, including the Wisconsin Card Sorting Test.

The TBI group consisted of archival data drawn from the files of clients having undergone neuropsychological assessments following traumatic brain injury. Psychometric test data from 30 individuals having suffered moderate or severe closed head TBI within the last five years was included in this study. In order to be classified as a moderate or severe injury, the lowest GCS of the participants must have been 12 out of a possible 15 or lower, the participants must have been unconscious for longer than 30 minutes, and the duration of PTA must have lasted longer than 1 hour. The injury had to have occurred not less than six months prior to the neuropsychological evaluation. The participants must not have had focal frontal lobe injuries, as evidenced by MRI brain scans. The first 30 participants that met inclusion criteria were selected (see Table 1).

Table 1:

A Summary of the Biographical Information of the Participants in the Traumatic Brain Injury Sample (Standard Deviations in brackets)

Group	Mean Age (Years)	Mean Number of Years of Education	Mean Lowest GCS Score (/15)	Mean Coma Duration (Days)	Mean PTA Duration (Days)	Time Since Injury (Months)
TBI Fatigue Group	32.93 (8.04)	12.20 (1.42)	8.60 (3.83)	8.54 (17.99)	40.07 (33.86)	38.13 (19.50)
TBI Non-Fatigue Group	30.93 (8.82)	12.53 (1.30)	8.71 (3.27)	8.94 (16.39)	33.53 (30.94)	32.80 (16.38)

The control group, which comprised, as far as possible, age and educationally matched non-organically compromised volunteers, was assessed using the same protocol as the above-mentioned experimental group. None of these participants had a history of head injury or neurological illness. This group consisted of 30 individuals. These individuals were obtained through purposive sampling of university students and the immediate community (see Table 2).

Table 2:

A Summary of the Biographical Information of the Participants in the Non-Traumatic Brain Injury Sample (Standard Deviations in brackets)

Group	Mean Age (Years)	Mean Number of Years of Education
Non-TBI Fatigue Group	27.07 (9.43)	15.33 (1.76)
Non-TBI Non-Fatigue Group	27.27 (9.02)	15.80 (1.74)

Exclusion criteria from the TBI sample included the presence of an aphasic disorder and/or a motor deficit of the dominant upper limb, which may have hampered performance on the verbal and the pen-and-paper tasks respectively. Patients that had focal frontal lesions and who would have been unable to complete the WCST successfully regardless of fatigue were excluded. This information was obtained through the collateral information: hospital records and brain scans, of the TBI individuals. Patients with previous neurological or psychiatric disease, including major illnesses, anxiety, depression, sleep disorders, or with known substance abuse disorders were also excluded. This information was obtained through questions during the semi-structured clinical interview (see appendix 4). This was to exclude possible confounding variables that may have had an impact on subjective fatigue. Furthermore, mild TBI individuals were excluded because most patients with mild TBI typically recover within weeks to months after injury especially if there are no complications, with only 15% of patients evidencing

disability at one year post-injury (Alexander, 1995). "The clinical deficits caused by neurologic injury can be understood as manifestations of impaired attention" (Alexander, 1995, p. 1253) – the cognitive deficits are secondary to attentional difficulties in mild TBI.

Procedure

Participants in the TBI group were tested individually in a clinical setting in sessions that lasted approximately 3 hours (two hours for the testing and one hour for the clinical interview). It was ensured that the same assessor had examined these individuals to eliminate inter-rater differences and that the assessment had occurred during the morning hours of the particular assessment day. This was to control for possible fatigue associated with testing in the afternoon hours.

A standard neuropsychological battery was used for all of the participants (see appendix 3). The standard fatigue test battery included (in order) the Digit Span Test (Wechsler, 1997), the UCLA-AVLT (Rey, 1964, as cited in Lezak, 1995; Schmidt, 1996), the WAIS-R Story Memory Test (Wechsler, 1997), the Controlled Oral Word Association Test (Schum, Sivan & Benton, 1989), the Trail Making test (*Army Individual Test Battery*, 1944), the Symbol Digit Substitution (Wechsler, 1981), the Tombaugh-Taylor Complex Figure Memory Test (Duley, Wilkins, Hamby, Hopkins, Burwell & Barry, 1992), the WAIS-R Arithmetic Test (Wechsler, 1997), the WAIS-R Block Design Test (Wechsler, 1997), the Stroop Colour-Word Interference Test (Golden, 1978), the Visual Analogue Scale for Fatigue (Lee, Hicks & Nino-Murcia, 1991), the Wisconsin Card Sorting Test (Berg, 1948; Grant & Berg, 1948) and the repeat of the Digit Span Test.

The standard non-fatigue test battery included (in order) the Digit Span Test, the Visual Analogue Scale for Fatigue, the Wisconsin Card Sorting Test, the UCLA-AVLT, the UNISA Story Memory Test, the Controlled Oral Word Association Test, the Trail Making test, the Symbol Digit Substitution, the Tombaugh-Taylor Complex Figure Memory Test, the WAIS-R Arithmetic Test, the WAIS-R Block Design Test, the Stroop Colour-Word Interference Test and the repeat of the Digit Span Test.

For the TBI participants, the clinical interview (see appendix 4) was conducted before the testing session. The participants in the non-TBI group were required to provide demographic information to ensure a matched group. This information was collected during a brief interview prior to the testing battery. Participants in the non-TBI group were then required to complete the standard neuropsychological battery in a two hour long testing session.

Participants in the TBI group were assigned to a fatigue (n = 15) or a non-fatigue condition (n = 15) based on the suitability of the assessment schedule adhered to at the time of their assessment. Those included in the non-fatigue group, as per standard procedure, completed the VAS-F, followed by the WCST, whilst they are not fatigued – prior to the administration of the extended neuropsychological test battery. Participants allocated to the fatigue group completed the neuropsychological battery over a period of approximately two hours, before completing the VAS-F and lastly, the WCST. Thus, the TBI participants were selected on the basis of those who completed the WCST near the start of their assessment and those who completed it near the end.

The question regarding the effects of fatigue had previously been identified by the researcher in the clinical practice and thus, the different testing strategies had been implemented. The researcher initiated

the two test protocols. The researcher then decided to examine the control sample to formalise the suspicion regarding the effects of fatigue on cognition. This was done because no assumption could be made about the effects of fatigue in a sample of TBI individuals without testing a sample of normal individuals. This research formally examined this particular question.

Participants in non-TBI group were randomly assigned to a fatigue (n = 15) or a non-fatigue condition (n = 15). Fatigue was induced through working on cognitively demanding tasks similar to those utilised in clinical assessment for approximately two hours. Only the neuropsychological tests of interest, including the Forward Digit Span Test, the Visual Analogue Scale for Fatigue and the Wisconsin Card Sorting Test, were scored. As all clinical cases initially complete the Forward Digit Span Task, this procedure was adhered to in the non-compromised control group. Again, as is the case in the clinical assessment, all participants were required to complete the Forward Digit Span Task one last time at the end of the two-hour testing session. It was ensured that the same assessor had examined the individuals in both the TBI and non-TBI groups to eliminate inter-rater differences. It was also ensured that the assessment had occurred during the morning hours of the particular assessment day. This was to control for possible fatigue associated with testing in the afternoon hours.

Instruments

Semi-structured Interview

All participants in the TBI group were involved in a clinical interview that lasted approximately one hour prior to the administration of the neuropsychological battery. The clinical interview was semi-structured and comprised open- and closed-ended questions (see Appendix 4). This was in order to establish biographical information, past medical history and more detailed information regarding the

injury. Participants in the non-TBI group, although not subjected to a formal interview, were questioned regarding important information, such as their age, educational background, lack of head injury or neurological illness etc. This was in order to ensure that they were matched as far as possible to the TBI group. This was also to ensure that they fulfilled all inclusion criteria and that no exclusion criteria were violated.

The Wisconsin Card Sorting Test

The Wisconsin Card Sorting Test (WCST) is a standard clinical measure of an individual's executive functioning. Successful performance on this test requires that one utilise cognitive flexibility, problem solving and the use of feedback to guide behaviour (Heaton, Chelune, Kay, Talley & Curtis, 1993). The WCST was originally developed to measure the conceptual level and conceptual abilities of the normal adult population. The WCST has come to be regarded as a sensitive measure of behavioural rigidity (Heaton, 1981).

The WCST has been shown to be reliable and valid in many different contexts and it has been extensively studied in many contexts. Validity research has suggested that patients with frontal lobe damage, and assumed consequent impairments of executive functioning, may perform worse on the WCST than do patients with focal brain damage in non-frontal regions. The focal frontal lobe damage groups tend to achieve lower numbers of category shifts and evidence higher levels of perseverative errors than do non-frontal groups (Anderson, Damasio, Jones & Tranel, 1991). These results suggests good criterion-related validity. Reliability research has yielded high inter-scorer reliabilities, with reliability coefficients > 0.94 (Milner, 1963).

A computerised version of the WCST was used (see appendix 5). In this computerised version of the test, participants were asked to match cards that vary by colour, shape and number to four target cards. Participants were not told how to sort the cards, but instead had to determine the correct category from feedback. The four target cards were presented in the upper half of the computer screen. These target cards differed from each other on the sorting dimensions (colour, shape and number of objects) and remained visible at all stages of the task. Every trial, a new sorting card was presented in the lower half of the computer screen. Participants sorted a card by placing it (clicking and dragging the card with the computer mouse) underneath any one of the four target cards. After a sorting response was made, a word appeared under the card that had just been sorted. The word "YES" was presented when the sort was correct and the word "NO" appeared when the sort was incorrect. The feedback stayed on the computer screen until participants sorted the next card. When participants discovered the sorting rule, the rule switched without notice after ten consecutively correct responses. The WCST ended when all 128 cards had been played, regardless of how many rule-switches had occurred. In this regard, this administration of the test differs from standard manual administration; the test was not discontinued after six sorts had been achieved (Milner, 1963).

Performance measures of the WCST were rated by the computer using the algorithms as proposed by Heaton (1981), which comprised perseverative errors, perseverative responses and non-perseverative errors (see Appendix 6). A large proportion of non-perseverative errors indicated that the participant did not adapt a reasoning strategy. Therefore, a criterion of 305 non-perseverative errors was used to exclude participants from further analyses (Somsen et al., 2000). The percentage of perseverative errors committed during the test was used as a measure of executive functioning. This variable has been shown to have sensitivity to brain damage, particularly frontal lobe lesions. Furthermore, the percentage of

perseverative errors is considered more purely executive than other variables from the WCST, such as the number of categories sorted or the percentage of non-perseverative errors (Lezak, 1995).

In terms of previous research of the reliability of the computerized version, Pearson's correlations of the manual and computerised version of the WCST were calculated. Using these alternate forms, test-retest reliability was 0.63 (Bowden, Fowler, Bell, Whelan, Clifford, Ritter, et al., 1998). Given this finding, the reliability of the computerised version is acceptable.

A weakness of the WCST is that in a study by Anderson et al. (1991), it was shown not to be either sensitive or specific as a measure of frontal lobe damage; no significant differences in WCST performance were found between participants with frontal lobe damage versus those with non-frontal lobe damage. Further analysis of the WCST performances associated with damage to various sub-regions of the frontal lobes also failed to reveal any reliable relationships. This indicates that performance on the WCST cannot be interpreted in isolation as an index of frontal lobe damage.

The Forward Digit Span

The control measure consisted of the Forward Digit Span Task (see appendix 7). On every trial of the Forward Digit Span Task, one digit was read out each second. After the digits were read out, the participant was required to repeat the digits in the same order back to the researcher. The task started with a three-digit sequence trial. If the participant correctly answered the trial, the next trial consisted of a sequence with one digit more. Otherwise, the next trial had an equal number of digits. The task ended when the participant failed to get two consecutive trials correct. The Forward Digit Span Task was measured at the beginning of the experimental session and again at the end of the session. The raw score

on the Forward Digit Span Task was taken as representing the capacity of the individual's short-term memory; the capacity to hold information in mind. This value was utilised in the statistical analyses.

Fatigue Manipulation

Fatigue was assumed to be induced through working on several, different, cognitively demanding, neuropsychological tasks (see appendix 3). The tasks required a high degree of mental effort. Sustained performance on the tasks was assumed to induce mental fatigue; working on cognitively demanding tasks for a considerable time often leads to mental fatigue (van der Linden, Frese & Sonnentag, 2003). This was deemed not to be harmful, but rather to approximate mental fatigue after a day in the office, which often involves working on several different tasks.

Subjective Fatigue

Subjective fatigue was reflected in the measured performance on the VAS-F (Lee, Hicks & Nino-Murcia, 1991), which consists of 18 items: 13 measuring the intensity of fatigue and 5 measuring the intensity of energy (see appendix 8). It is a visual analogue scale that measures instantaneous fatigue. Participants were required to read each statement and respond by placing an "X" along a 100mm line in a position that they felt best represented their current state. This was measured in millimeters for each item. A total fatigue score on this measure was then obtained and this value was utilised in the analyses.

The authors consider the VAS-F to be valid and reliable in non-pathologic and pathologic populations. Pearson correlations have been used to establish concurrent validity of the VAS-F with the Stanford Sleepiness Scale (SSS) and the Profile of Mood States (POMS). The VAS-F compares favorably with the SSS and the POMS and it's internal consistency reliabilities are high. Cronbach's α for the 13-item

fatigue subscale is 0.91. Cronbach's α for the 5-item energy subscale is 0.94. To establish the ability of the VAS-F to distinguish fatigue and energy from other aspects of mood state, associations with the four other subscales of the POMS were tested. The VAS-F fatigue and energy subscales were not significantly correlated with POMS subscales related to depression, tension, or anger (Lee, Hicks & Nino-Murcia, 1991).

A weakness/limitation of this self-report instrument is the hesitation some persons have in using the extreme ends of the 100mm lines. This measure relies on self-report; individual differences on such things as response biases and expectations about how one feels versus how one should feel may significantly influence reports of fatigue. Another limitation concerns the motor and visual abilities of the patient. Patients with tremors, paralysis or visual impairments are unable to complete any type of visual analogue scale reliably (Lee, Hicks & Nino-Murcia, 1991).

Ethical Considerations

The data for the first group, the participants with TBI (both fatigue and non-fatigue groups), were cases that had already been tested as part of an on-going clinical practice. It is standard practice that these individuals sign consent forms prior to their evaluations. The individuals were aware at the time that they were tested that their results may be used for the purposes of research and they specifically granted their permission for this possibility.

Because the individuals were tested in clinical practice, the ownership of the data remains with the practitioner. The psychologist in charge of the clinical practice has given his informed

consent/permission for this data to be analysed (see appendix 9). Thus, the cases that have already been through testing were compared; the participants tested in one standard order were compared to those tested in the alternate standard order.

The data for the control group consisted of the volunteer participants with no history of TBI. These individuals were given information sheets (see appendix 10) and were required to sign consent forms (see appendix 11) prior to their evaluations, giving their permission to use their data for research purposes.

All information that may identify participants has been removed from the research report; thus, confidentiality has been ensured. No names or identifying information have been included in the research report. Furthermore, names and identifying information will not be published elsewhere. Unavoidably, the researcher knows the identity of the participants and anonymity is not possible.

There were no risks involved for the participants, as both the clinical interview and the neuropsychological tests that were used are deemed to be non-invasive, low-risk instruments that are not likely to evoke psychological disturbance.

Ethical clearance was first granted from formal structures within the University of the Witwatersrand (see Appendix 12).

Results

In terms of the structure of the results, the reliability of the instruments that were utilised in this research is initially addressed. Descriptive statistics for each of the variables of interest are then provided. The issue of the normality of the raw data is then addressed. Thereafter, the variables of interest are used as a structure for the presentation of the findings of this research. The chapter ends with the provision of the power of the measures of the variables of interest.

Instrument Reliability

In order to establish instrument reliability, Pearson's correlations were performed on the Forward Digit Span Test, comparing pre- and post-manipulation performance ($n = 60$). Performance on the Forward Digit Span Test before and after the manipulation was highly correlated ($r = 0.94$). This led to the assumption that test-retest reliability was good.

It was not feasible to conduct Cronbach's α on the Wisconsin Card Sorting Test because the assumptions for this calculation were not met. In order to calculate a meaningful Cronbach's α, each test item needs to act as if the test taker has no prior experience with it; all items need to be independent of each other. However, this is not the case on the WCST, as previous behaviours guide test-takers' behaviour on subsequent test items.

Descriptive Statistics

Means (M) and standard deviations (S) were calculated separately for the four groups for each of the variables of interest (see Table 3): mean fatigue, mean number of sorts, mean percent perseveration,

mean percent non-perseverative errors, mean number of failures to maintain set, forward digit span pre-manipulation and forward digit span post-manipulation.

Table 3:

Means of the Variables of Interest of the Experimental Tasks

(Standard Deviations in Brackets)

	TBI Non-Fatigued Group (n = 15)	TBI Fatigued Group (n = 15)	Non-TBI Non-Fatigued Group (n = 15)	Non-TBI Fatigued Group (n = 15)
VAS-F Fatigue	0.48 (0.25)	0.51 (0.25)	0.45 (0.22)	0.53 (0.28)
WCST Number of Sorts	5.07 (2.37)	4.20 (2.11)	6.20 (2.31)	6.80 (2.83)
Percent Perseveration	20.79 (8.63)	30.07 (14.79)	16.87 (9.53)	13.40 (8.99)
Percent Non-Perseverative Errors	23.14 (11.29)	21.20 (8.87)	17.60 (5.72)	16.53 (6.06)
Failures to Maintain Set	0.71 (0.91)	0.87 (1.06)	1.00 (1.07)	1.07 (1.28)
Forward Digit Span Test Digit Span (pre-manipulation	6.43 (1.22)	6.73 (1.53)	7.13 (1.03)	7.00 (1.00)
Digit Span (post-manipulation	6.36 (1.22)	6.80 (1.52)	7.27 (1.16)	7.20 (1.01)

Biographical Data Comparisons

In terms of age, the four groups were not significantly different from each other ($t = 4.74$; $p = 0.13$). Furthermore, despite the fact that the non-TBI participants tended to have higher levels of education than the TBI participants, the four groups were not significantly different from each other ($T = 0$; $p = 0.25$). Thus, the groups were deemed to be appropriately matched in terms of age and education.

Normality of the Raw Data

The raw data was subjected to Kolmogorov-Smirnov test ($n = 60$) to determine if the data was normally distributed (see Table 4). The distribution of residuals of the raw data for each dependent variable ($n = 60$) were also analysed for normality (see appendix 13).

Table 4:

Goodness of Fit for Normal Distribution

Dependent Variable	Kolmogorov-Smirnov (D =)	Significance (p =) *Significant at 5%
Mean Fatigue	0.017	<0.01*
Mean Number of Sorts	0.11	0.065
Mean Percentage Perseveration	0.15	<0.01*
Mean Percentage Non-Perseverative Errors	0.20	<0.01*
Mean Number of Failures to Maintain Set	0.25	<0.01*
Mean Pre-Manipulation Digits Forward	0.12	0.039*
Mean Post-Manipulation Digits Forward	0.17	<0.01*

As can be seen, the data for the variables 'mean fatigue', 'mean percentage of perseverative errors', 'mean percentage of non-perseverative errors', 'mean number of failures to maintain set', 'mean pre-manipulation digits forward' and 'mean post-manipulation digits forward' were normally distributed. Because this data was normally distributed, parametric tests were deemed appropriate (Howell, 2004).

The Control Measure

A repeated measures ANOVA was conducted on the control measure, the Forward Digit Span Test. The independent variables were TBI vs. no TBI and fatigue vs. no fatigue. Performance on the Forward Digit Span Test was the repeated measure in the analysis; it was measured before and after the fatigue manipulation. It was expected that fatigue would not affect performance on the Forward Digit Span Test.

Pre-digits forward performance was not significant ($F = 2.38$; $p = 0.13$) between groups. That is individuals with TBI and individuals without TBI did not perform significantly differently on the Forward Digit Span Test prior to the fatigue manipulation. However, post-digits forward between groups was significant ($F = 4.46$; $p = 0.039$). That is, individuals with TBI and individuals without TBI performed significantly differently on the Forward Digit Span Test after the fatigue manipulation. Thus, the control measure was a confounder and had to be included in further analyses of the dependent variables as a covariate.

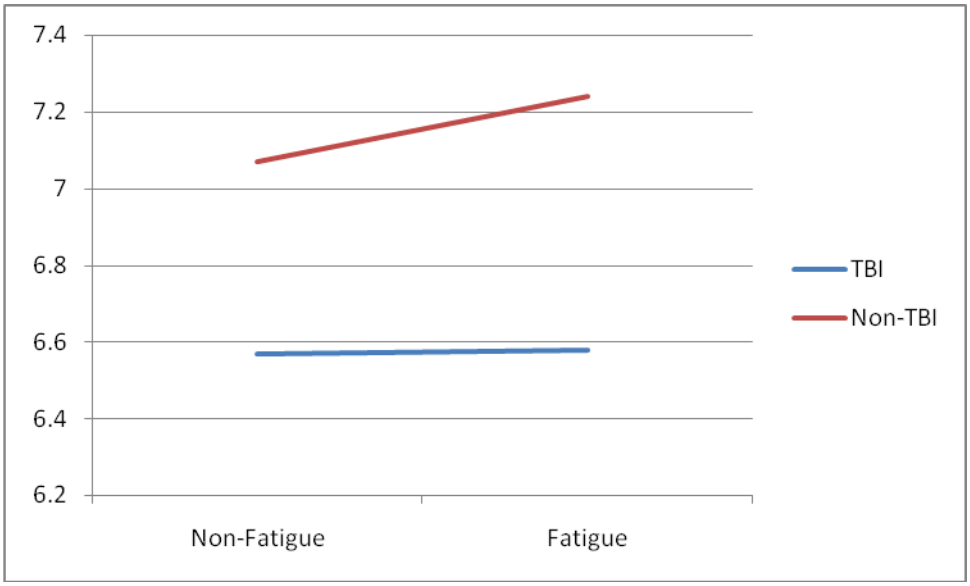


Figure 1. A Line Graph Showing TBI and Non-TBI Individuals' Mean Performance on the Forward Digit Span Test Before and After the Fatigue Manipuation

Analysis of the Dependent Variables

A 2 way ANCOVA was conducted with each dependent variable. The two independent variables were between subject variables – TBI vs. no TBI, and fatigue vs. no fatigue. This served to investigate the effect of the independent variable of fatigue on the dependent variables, the effect of the independent variable of TBI on the dependent variables and whether there was an interaction effect. The covariate in this analysis was performance on the Forward Digit Span Test. The dependent variables included the fatigue score, the number of card sorts, the percentage of perseverative errors, the percentage of non-perseverative errors and the number of set maintenance failures.

The Wisconsin Card Sorting Test

Number of Card Sorts

In order to investigate whether mental fatigue was associated with reduced inductive reasoning, the dependent variable, number of sorts, was examined. The mean number of sorts was significant between individuals with TBI and individuals without TBI ($F = 9.63$; $p = 0.003$). That is, individuals with TBI performed significantly differently from individuals without TBI. The number of sorts was not significantly different between fatigued and non-fatigued individuals ($F = 0.01$; $p = 0.92$). There was no interaction effect between TBI and fatigue on the number of sorts ($F = 1.14$; $p = 0.29$) (see Figure 2).

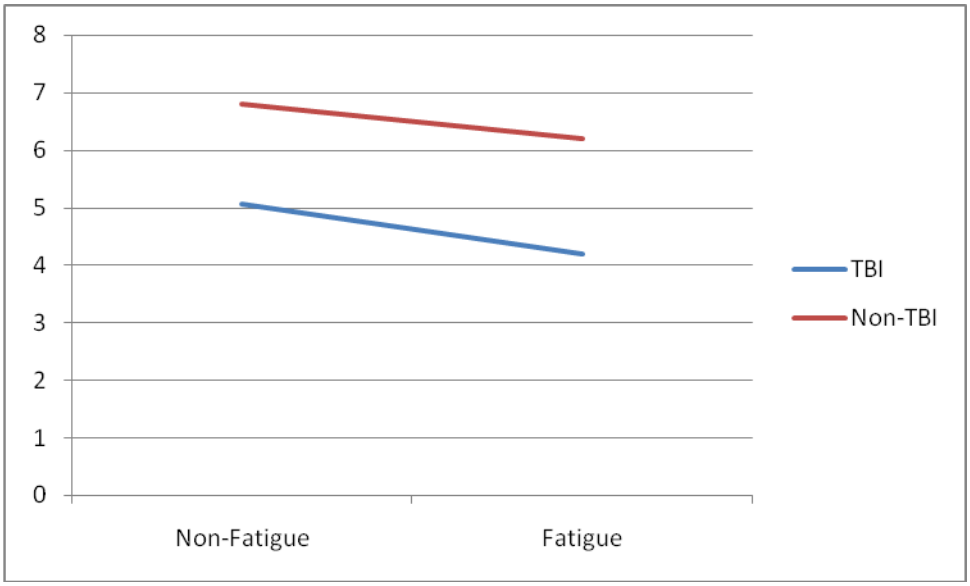


Figure 2. A Line Graph Showing TBI and Non-TBI Individuals' Mean Number of Sorts Before and After the Fatigue Manipuation

Mental fatigue did not significantly impact on inductive reasoning, as operationalised by the mean number of sorts. However, there was a trend towards less inductive reasoning when fatigued in both TBI

and non-TBI individuals (see Figure 2). Furthermore, individuals with TBI evidenced significantly reduced inductive reasoning compared to individuals without TBI. Given the vast literature of the construct validity of the WCST (Heaton, 1981; Kimberg & Farah, 1993; Milner, 1963; Norman & Shallice, 1986, as cited in van der Linden, Frese & Meijman, 2003), the difference in performance between the TBI and non-TBI group on this variable is likely to be a factor of compromise of the brain. It is unlikely that the difference in performance is a factor of level of intelligence as might be implied by the mean level of education in the two groups. The reason being that education has been found to affect performance only to a small degree in previous research (Boone et al., 1993).

Percent Perseveration

In order to investigate whether mental fatigue was associated with reduced cognitive flexibility, the dependent variable, percent perseveration, was examined. The mean percentage of perseverative errors was significant between individuals with TBI and individuals without TBI ($F = 14.58$; $p = 0.0003$). That is, individuals with TBI performed significantly differently from individuals without TBI. The percentage of perseverative errors was not significantly different between fatigued and non-fatigued individuals ($F = 0.82$; $p = 0.37$). There was, however, an interaction effect between TBI and fatigue on the percentage of perseverative errors ($F = 4.61$; $p = 0.036$) (see Figure 3).

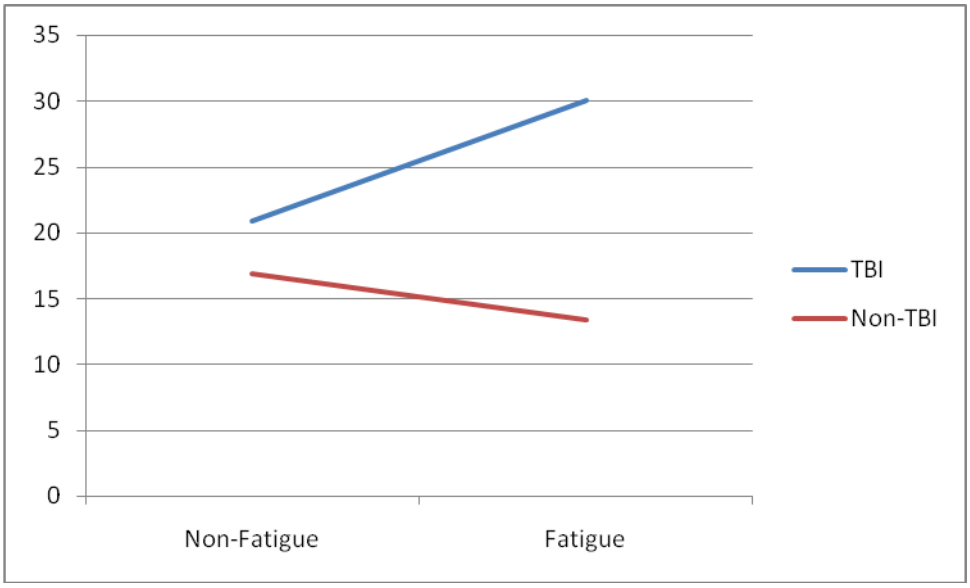


Figure 3. A Line Graph Showing TBI and Non-TBI Individuals' Mean Percent Perseveration Before and After the Fatigue Manipuation

Fatigue was expected to coincide with increased perseveration. Mental fatigue did not significantly impact on cognitive flexibility, as operationalised by the percentage of perseverative errors. However, as can be seen in Figure 3, there was a trend for increased perseveration in TBI individuals. This trend was not consistent in individuals without TBI.

Individuals with TBI evidenced significantly reduced cognitive flexibility compared to individuals without TBI – the mean percent of perseverative errors was much higher for TBI individuals than for individuals without TBI. Furthermore, there was an interaction effect, whereby fatigue impacted cognitive flexibility to a greater extent in TBI individuals than those without TBI.

Percent Non-Perseverative Errors

In order to investigate whether mental fatigue was associated with reduced conceptual abilities, the dependent variable, percentage of non-perseverative errors, was examined. The percentage of non-perseverative errors was significantly different between individuals with TBI and individuals without TBI ($F = 5.35$; $p = 0.024$). That is, individuals with TBI performed significantly differently from individuals without TBI. The percentage of non-perseverative errors was not significantly different between fatigued and non-fatigued individuals ($F = 0.38$; $p = 0.54$). There was no interaction effect between TBI and fatigue on the Percentage of Non-Perseverative Errors ($F = 0.1$; $p = 0.91$) (see Figure 4).

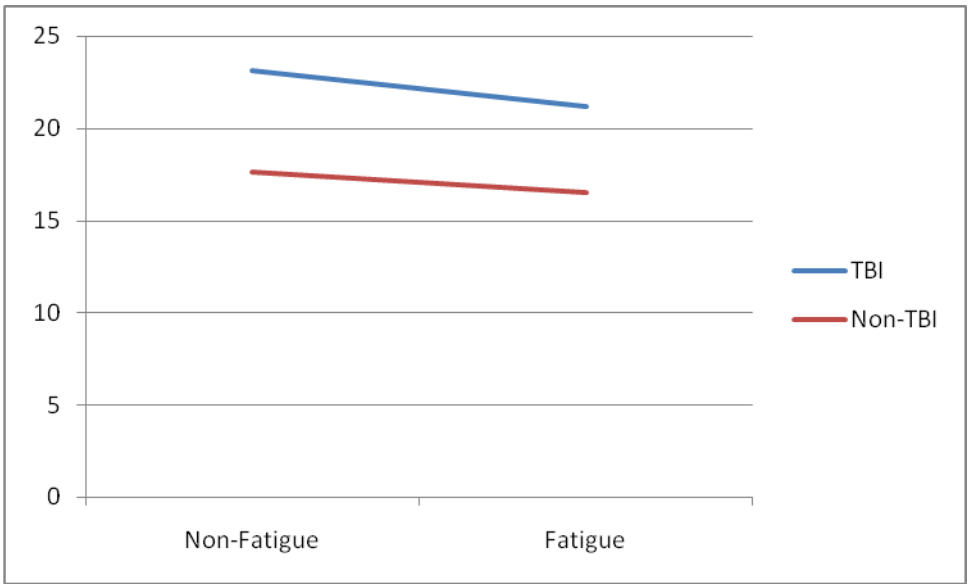


Figure 4. A Line Graph Showing TBI and Non-TBI Individuals' Mean Percent Non-Perseverative Errors Before and After the Fatigue Manipuation

Mental fatigue did not significantly impact on conceptual abilities, as operationalised by the percentage of non-perseverative errors. Unexpectedly, there was a trend for both individuals with and without TBI towards fewer non-perseverative errors when fatigued. Individuals with TBI evidenced significantly reduced conceptual abilities compared to individuals without TBI. As previously discussed, the difference in performance between the TBI and non-TBI group on this variable is more likely to be a factor of compromise of the brain than a factor of level of education in the two groups.

Number of Failures to Maintain Set

In order to investigate whether mental fatigue was associated with a decrease in attentional capacity or distractibility, the dependent variable, number of failures to maintain set, was examined. The number of failures to maintain set was not significant between individuals with TBI and individuals without TBI ($F = 0.91$; $p = 0.35$). That is, individuals with TBI did not perform significantly differently from individuals without TBI. The number of failures to maintain set was not significantly different between fatigued and non-fatigued individuals ($F = 0.23$; $p = 0.63$). There was no interaction effect between TBI and fatigue on the number of failures to maintain set ($F = 0.06$; $p = 0.81$) (see Figure 5).

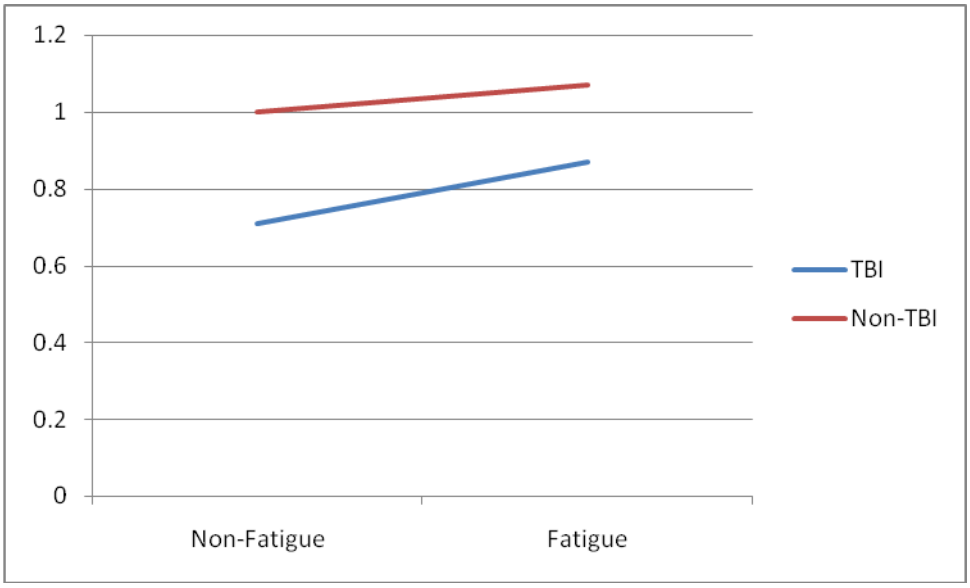


Figure 5. A Line Graph Showing TBI and Non-TBI Individuals' Mean Number of Failures to Maintain Set Before and After the Fatigue Manipuation

Individuals with TBI did not perform significantly differently compared to individuals without TBI. The number of failures to maintain set was used as a measure of sustained attention in order to rule out attention problems due to fatigue, which could impact on other results. Mental fatigue did not significantly impact on attentional capacity or distractibility, as operationalised by the mean number of failures to maintain set, implying that mental fatigue did not significantly impact on sustained attention. However, as can be seen from Figure 5, there was a trend towards increased failures to maintain set in both individuals with TBI and those without when fatigued; there was a trend towards increased distractibility when fatigued.

Fatigue

The mean fatigue score on the VAS-F was not significantly different between individuals with TBI and individuals without TBI ($F = 0.44$; $p = 0.51$). That is, individuals with TBI did not score significantly differently from individuals without TBI. The mean fatigue score was not significantly different between fatigued and non-fatigued individuals ($F = 0.73$; $p = 0.39$). There was no interaction effect between TBI and fatigue on the Mean Fatigue score ($F = 0.12$; $p = 0.73$) (see Figure 6).

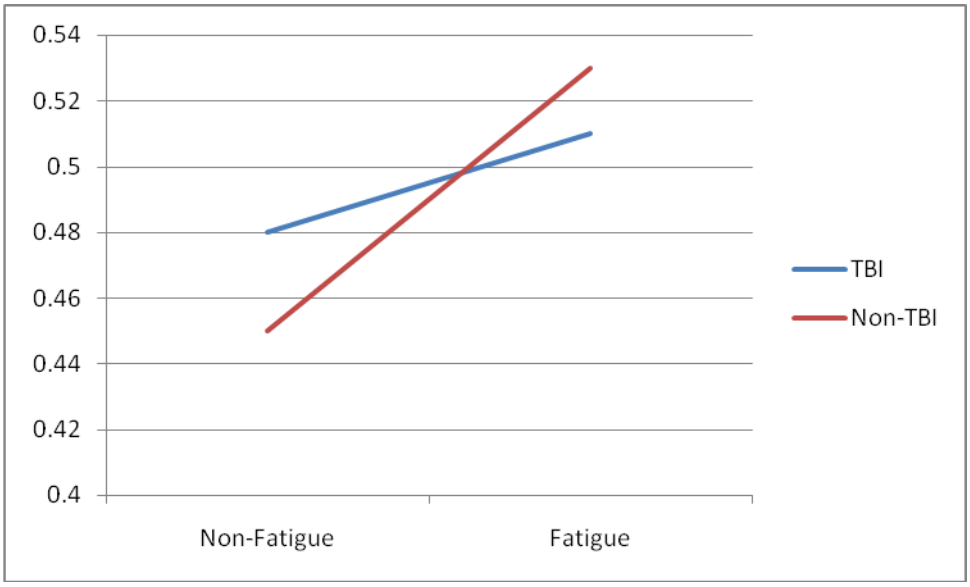


Figure 6. A Line Graph Showing TBI and Non-TBI Individuals' Mean Subjective Ratings of Fatigue Before and After the Fatigue Manipuation

This analysis suggests that fatigue increased in both individuals with TBI and those without TBI - the increase was not significantly different - in all of the groups. The fatigue manipulation did not have a significantly greater impact on non-TBI than TBI individuals. Nonetheless, based on the trends evident in the data (see figure 6), this would suggest that the fatigue manipulation was successful in increasing

participants' level of subjective fatigue after working on cognitively demanding tasks for approximately two hours.

Analysis of the Control Measure: The Forward Digit Span Test

In order to investigate whether the ability to hold information in mind was free from the effects of mental fatigue, performance on a simple, short-term memory test, the Forward Digit Span Test, which is independent of executive control, was examined. The Forward Digit Span Test was administered before and after the fatigue manipulation. It was expected that fatigue would not affect digit span performance.

In order to test this, the Forward Digit Span Test was submitted to a repeated measures ANOVA. Performance on the Forward Digit Span Test was the repeated measure in the analysis; it was measured before and after the fatigue manipulation. The independent variables were TBI vs. no TBI and fatigue vs. no fatigue.

It was found that pre-manipulation Digits Forward was not significant ($F = 2.38$; $p = 0.13$) between groups. That is, individuals with TBI and individuals without TBI did not perform significantly differently on the Forward Digit Span Test prior to the fatigue manipulation. However, post-manipulation Digits Forward between groups was significant ($F = 4.46$; $p = 0039$). That is, individuals with TBI and individuals without TBI performed significantly differently on the Forward Digit Span Test after the fatigue manipulation.

There was no significant main effect of fatigue, which showed that the fatigued and non-fatigued groups did not perform significantly differently on the second administration than on the first. However, in

opposition to expectations, there was a significant interaction effect, showing that TBI affected short-term memory performance worse when these participants were fatigued compared to individuals without TBI.

Power

Power refers to the probability of correctly rejecting a false null hypothesis. A more powerful experiment is one that has a greater probability of rejecting a false null hypothesis than does a less powerful one (Howell, 2004).

Cohen's D for non-TBI individuals for Mean Fatigue is -0.31, which is small.

Cohen's D for TBI individuals for Mean Fatigue is -0.12, which is small.

Cohen's D for non-TBI individuals for Number of Card Sorts is -0.25, which is small.

Cohen's D for TBI individuals for Number of Card Sorts is 0.36, which is small.

Cohen's D for non-TBI individuals for the Percentage of Perseverative Errors is 0.34, which is small.

Cohen's D for TBI individuals for the Percentage of Perseverative Errors is -0.80, which is large.

Cohen's D for non-TBI individuals for the Percentage of Non-Perseverative Errors is 0.13, which is small.

Cohen's D for TBI individuals for the Percentage of Non-Perseverative Errors is .24, which is small.

Cohen's D for non-TBI individuals for the number of set maintenance failures is -0.06, which is small.

Cohen's D for TBI individuals for the number of set maintenance failures is -0.15, which is small.

A possible explanation for the predominance of small power of the measures is the small sample sizes in this research study. In order to obtain higher levels of power of the measures, one may require a greater number of subjects in each of the groups; sample size should be increased.

Discussion

The present study was directed at an examination of the executive control of behaviour in an organically compromised population and in an organically uncompromised population. This study also aimed to answer the question as to whether fatigue, as measured by a subjective questionnaire, negatively impacts on executive control. Executive control, which refers to the ability to sustain attentional capacity as required to regulate perceptual and motor processes in order to facilitate the inductive reasoning required to respond in an adaptive way to changing task demands (Baddeley & Logie, 1999, as cited in van der Linden, Frese & Meijman, 2003), was operationalised as decreased cognitive flexibility and increased perseveration as measured by the Wisconsin Card Sorting Test (WCST).

Performance on the WCST was used as a measure of the effect of sustained cognitive activity in fatigued individuals both with and without TBI. Furthermore, performance was used as a baseline for the non-fatigued TBI individuals. This was done as a means to address the issue of chronic fatigue as a factor of TBI irrespective of activity; some TBI individuals complain they wake up tired and stay that way even after rest and relaxation.

Performance of Organically Compromised and Uncompromised Individuals on the WCST

Consistent with expectations, and further confirming the construct validity of the WCST, individuals with TBI performed significantly worse than organically uncompromised individuals on all of the aspects of this measure that were examined, except for the variable of the numbers of failures to maintain a response set. The individuals that had sustained TBI did not suffer any focal frontal damage, as confirmed by collateral information and brain scans. Nevertheless, their performance on this measure

was truncated compared to healthy individuals. All of the TBI individuals had suffered diffuse axonal injury. It may be the case that, in the organically compromised participants, the scattered white matter damage reduced the efficacy of information processing in the frontal lobes of the brain, leading to impoverished performance on this sensitive and specific measure (Baddeley & Logie, 1999, as cited in van der Linden, Frese & Meijman, 2003).

In this study, the effects of education were assumed to play an insignificant, minor role. The reason being that education has in previous research been found to affect performance only to a small degree (Boone et al., 1993).

Individuals with TBI evidenced significantly reduced inductive reasoning compared to individuals without TBI. They achieved a lower number of shifts in the sorting rule overall compared to organically uncompromised individuals. Individuals with TBI also evidenced significantly reduced cognitive flexibility compared to individuals without TBI. Thus, the individuals with TBI perseverated in their answers and had substantial difficulty relinquishing a response set when it was no longer appropriate compared to individuals with no history of TBI. Additionally, individuals with TBI evidenced significantly reduced conceptual abilities compared to individuals without TBI. They made a greater number of errors on this measure, indicating impoverished conceptualisation of the nature of the problem.

The Fatigue Manipulation

In order to measure subjective levels of fatigue in the participants, a self-report, visual analogue scale of fatigue was used. Non-fatigued individuals in both the TBI and non-TBI groups completed the scale

prior to the fatigue manipulation. Fatigued individuals in both TBI and non-TBI groups completed the scale after the fatigue manipulation. Levels of fatigue were subjectively higher in all individuals after the two hours of working on cognitively demanding tasks. However, individuals with TBI did not score significantly differently from individuals without TBI on the subjective rating scale of fatigue. This analysis suggests that fatigue was greater in all of the groups after the fatigue manipulation. This trend in the results (see figure 6) indicated that the fatigue manipulation was successful in increasing participants' level of subjective fatigue after approximately two hours of working on cognitively demanding tasks irrespective of organic status.

The Effects of Fatigue on Executive Functioning

This study specifically examined whether mental fatigue coincides with compromised executive control. Executive control depends on the ability to hold goals and goal-related information active in mind so that they can exert their influence on the selection of actions (Kimberg & Farah, 1993). The reduced performance on the WCST of fatigued participants appeared to be caused by difficulties upholding sufficient levels of executive control during the task.

The Effects of Fatigue on Inductive Reasoning

Fatigue was expected to coincide with a lower number of discovered sorting rules on the WCST and reduced inductive reasoning. The results of this study showed that mental fatigue did not significantly impact on inductive reasoning. However, there was a trend towards reduced inductive reasoning when the participants were fatigued. This trend held true for both TBI and non-TBI individuals. Thus, fatigue negatively impacted on the capacity for inductive reasoning for both organically compromised and uncompromised individuals.

The Effects of Fatigue on Cognitive Flexibility

In the WCST, lowered cognitive flexibility in task behaviour is operationalised as perseveration. Fatigue was expected to coincide with increased perseveration and reduced cognitive flexibility. It was expected that despite continual feedback that the manner in which one was responding was incorrect, the participants would continue to respond in this mal-adaptive, perseverative manner. The results of this study showed that mental fatigue did not significantly impact on cognitive flexibility. However, there was a trend towards reduced cognitive flexibility and increased perseveration in fatigued individuals. Compared to non-fatigued TBI participants, fatigued TBI participants made more perseverative errors on the WCST, which implies that they repeatedly tried to sort cards according to a rule that had already proved faulty in earlier sorting attempts. Fatigued TBI participants showed more performance deficits than non-fatigued participants on tasks that required the flexible generation and testing of hypotheses. This trend was not consistent in non-TBI individuals. Thus, fatigue impacted cognitive flexibility to a greater extent in TBI individuals than in individuals that were not organically compromised.

This result is consistent with previous research that has been conducted. The results of the study by van der Linden, Frese and Meijman (2003) on a sample of TBI patients showed that, compared to a non-fatigued group, fatigued participants displayed more perseveration on the WCST. These findings indicate compromised executive control under fatigue, which may explain the typical errors and sub-optimal performance that are often found in fatigued people.

The goal-activation perspective states that during perseveration, the representations of task goals themselves may be unaffected, yet their activation may be too low to exert influence on the selection of

actions (Duncan et al., 1996). This means that the TBI participants may perseverate even if they are aware that their current actions are no longer appropriate. Although this study did not examine the extent to which fatigued participants were aware of the inappropriateness of their actions during perseveration, it is assumed that they perceived the feedback after a sorting attempt. Namely, after each trial, obvious feedback was provided. This feedback stayed on the screen until participants continued with the next trial. Thus, even the fatigued TBI participants must have noticed that their sorting actions had not been successful; nevertheless, they evidenced perseveration.

The above-mentioned results suggest that the deficits in task performance in the areas of inductive reasoning and cognitive flexibility of fatigued participants were caused by difficulties in upholding sufficient levels of executive control during the tasks (Duncan et al., 1996). In general, perseveration on the WCST may arise from inadequate integration of task feedback for the selection of responses (Heaton, 1981). This may also be responsible for the low number of discovered sorting rules and reduced inductive reasoning for fatigued participants. Thus, these aspects of executive control were hampered by fatigue.

The Effects of Fatigue on Conceptual Abilities

A further expectation of this study was that fatigue would result in reduced conceptual abilities; that fatigue would hamper the conceptual abilities of participants. In this study, mental fatigue did not significantly impact on conceptual abilities. In opposition to expectations, there was a trend towards fewer non-perseverative errors for both individuals with and without TBI when fatigued. An explanation for this unexpected result may be that the errors that were made were perseverative in nature, and not non-perseverative in nature. Thus, as increased numbers of perseverative errors were made when

participants were fatigued, there were fewer non-perseverative errors committed. Furthermore, fatigued participants did not show a trend towards an increased number of non-perseverative errors compared to non-fatigued participants. This implies that perseverative errors were the most reliable effects of fatigue.

The Effects of Fatigue on Sustained Attention

The number of set maintenance failures was used as a measure of sustained attention. Mental fatigue did not significantly impact on attentional capacity or distractibility. Nevertheless, there was a trend towards an increased number of failures to maintain set in both individuals with TBI and those without TBI when fatigued; there was a trend towards increased distractibility when fatigued.

Diffuse axonal injury, a mechanism of primary head injury, which results in diffuse white matter lesions, is responsible for the slowing down of information processing and for reducing available attention resources (Azouvi et al., 2004; Ponsford & Kinsella, 1992). Available attention resources are reduced in this type of diffuse axonal injury. This appears to come to the fore more predominantly when the individuals are fatigued. Additionally, as a result of the slowed processing resulting from many microscopic sites of diffusely distributed damage, activities that were automatic now may only be accomplished with deliberate effort, which further reduces the capacity for sustained attention. Activities that are performed frequently during the day, such as concentrating, may become effortful. Compounding matters is that as individuals with TBI become fatigued their efficiency levels plummet so that activities that were difficult when they were rested now become extremely laboured and more error prone and their ability to sustain attention is truncated.

The coping hypothesis which was proposed by van Zomeren, Brouwer and Deelman (1984) to explain fatigue after TBI, contends that fatigue is secondary to cognitive impairment. Fatigue, in this regard, is due to the constant effort that TBI individuals need to exert to meet the demands of daily life and to compensate for slowed processing and attentional impairments as a result of brain injury and subsequent neuronal damage or death. To perform a cognitive task would require a high degree of mental effort, which could lead to a sensation of fatigue. Several authors have experimentally studied the coping hypothesis. Riese et al. (1999) hold that there is an increased psychophysiological cost for TBI patients to perform cognitive tasks than there is for individuals with no history of a head injury.

The Effects of Fatigue on the Ability to Hold Information in Mind

In order to investigate whether the ability to hold information in mind was free from the effects of mental fatigue, performance on a simple, short-term memory test, the Forward Digit Span Test, which is independent of executive control, was examined. The Forward Digit Span Test was administered before and after the fatigue manipulation. It was expected that fatigue would not affect performance on this measure. It was found that individuals with TBI and individuals without TBI did not perform significantly differently on the Forward Digit Span Test prior to the fatigue manipulation. However, individuals with TBI and individuals without TBI performed significantly differently on the Forward Digit Span Test after the fatigue manipulation. Thus, fatigue affected short-term memory functioning of TBI individuals to a greater extent than individuals without TBI. This implies that fatigue did impact on the ability to hold information in mind, particularly in participants with TBI. The capacity to hold information active in mind is thought to be free from executive control processes, but rather, relies on the maintenance and reproduction of information (Norman & Shallice, 1986, as cited in van der Linden,

Frese & Meijman, 2003). It would appear that fatigue results in a general reduction in cognitive functioning in participants with TBI, with both executive and non-executive functions being affected.

Working on cognitively demanding tasks for a considerable time often leads to mental fatigue, which impacts negatively on task performance. The way in which the cognitive control of behaviour changes under fatigue is unclear. Some researchers proposed that mental fatigue affects those control processes that are involved in the organisation of actions and that play a major role in deliberate and goal-directed behaviour; this is the control view of fatigue (Bartlett, 1943). Another relevant finding in fatigue research that supports the 'control view' is that performance on simple or well-learned tasks, which can be executed in a more or less automatic way, can be upheld over long periods of time, after sleep deprivation, or after mentally demanding activities. On the other hand, complex tasks that require the deliberate control of behaviour are generally difficult to perform under such circumstances (Broadbent, 1979). These typical effects on different levels of information processing are found in several fatigue studies, and the specific disorganisation of behaviour that tends to occur under fatigue, both suggest that mental fatigue is mainly characterised by the deterioration of executive control (Baddeley & Logie, 1999, as cited in van der Linden, Frese & Meijman, 2003). However, the results of this study suggest that even more automatic processes, such as the ability to hold information in mind, were affected by fatigue. Fatigue appears to hamper the efficacy of global cognitive functions, not only those functions associated with executive control.

The Post-Concussion Syndrome

An inference that can be made from the results of this study is that fatigue, which is one of the somatic symptoms of post-concussion syndrome (PCS), is related to neuropsychological functioning in non-TBI

individuals. This study showed that fatigue impacts negatively on inductive reasoning in individuals with no history of TBI. This trend also held true for individuals with TBI: fatigue is related to neuropsychological functioning in TBI individuals. Thus, fatigue has substantial implications for optimal cognitive functioning, even in organically uncompromised individuals that are better equipped cognitively to compensate for these effects.

Indeed, PCS symptoms are not specific to brain injured patients and can occur in people that do not have a history of a brain injury. Previous research has shown that people with no history of head injury endorse relatively high base rates of PCS symptoms, including fatigue (Chan, 2001). It is thought that non-brain injury populations suffer from PCS complaints and fatigue due to issues such as study, work, stress and emotional state in everyday life (Wang, Chan & Deng, 2006).

A previous study comparing healthy individuals that report high levels of PCS symptoms and a sample of TBI patients with PCS revealed that the patients performed significantly worse on neuropsychological functions than the healthy, high symptom reporters, despite non-significant differences in symptom endorsement between these two groups. Wang, Chan and Deng (2006) demonstrated that the base rate of PCS symptoms in a group of healthy university students is relatively high and that PCS is not related to neuropsychological functions in normal people. There was no difference in the performance of neuropsychological functions between healthy people with PCS and those without PCS. It was inferred from this study that it is not the PCS symptoms, but the brain injury, that causes cognitive impairment in TBI patients. Consistent with this study, healthy individuals reported high levels of fatigue in this investigation. However, the present study showed trends that certain neuropsychological functions were affected by fatigue in healthy individuals, which was inconsistent with the authors' results. By

implication, the results of the current study indicate that fatigue hampers optimal cognitive functioning in both organically compromised and uncompromised individuals.

Bohnen, Jolles and Twijnstra (1992) reported inconsistent associations between cognitive impairment and the reporting of PCS in TBI patients. Wang, Chan and Deng, (2006) found no significant differences in neuropsychological performance between TBI high symptom reporters and TBI low symptom reporters. This means that the high symptom reporters did not perform significantly worse in any cognitive domain than the low symptom reporters. The present study did not support these results. Instead, the current study showed that there were differences in neuropsychological performance between fatigued and non-fatigued TBI participants. Fatigued individuals were less capable of optimal cognition.

Supporting the results of the present investigation, there have been empirical studies of brain injured patients with PCS that have shown that these patients perform more poorly on neuropsychological tests than TBI patients without PCS and thus, might have more cognitive impairments than the latter group (Bohnen et al., 1995). Gronwall and Wrightson (1974) found reduced cognitive efficiency on some neuropsychological measures, including the Paced Auditory Serial Attention Test, in ten patients with head trauma and subjective PCS in comparison to the performance of a patient group with head injury to the same degree but without the subjective syndrome.

Practical Implications of Fatigue

Given the cognitive effects of fatigue and the reduced ability of TBI individuals to compensate for these effects, fatigue is a major factor that adversely impacts on the rehabilitation process (Lee, Hicks & Nino-

Murcia, 1991). Given this understanding, rehabilitation therapists should address cognitive rehabilitative efforts in the morning hours of the day, when participants are less likely to be fatigued. This would lead to increased efficacy of cognitive rehabilitative efforts.

Following the rehabilitative efforts, individuals are likely to attempt a return to work or school. Based on the cognitive difficulties associated with fatigue, this will place restrictions on an uncompromised return to the workplace or school environment. The individual may need to attempt working half-day initially. If the individual is subjectively and objectively coping, then the demands may be increased in a systematic and monitored manner. Thus, reduced working hours, supervision or a structured programme is likely to enable them to work more efficiently.

Strengths of this Study

In the current study, fatigue was induced by using tasks that were different from the experimental task. Thus, the effects of mental fatigue were measured between-tasks instead of within-tasks. The advantage of this approach is that the tasks after the fatigue manipulation were novel and were expected to put heavy demands on executive control. Additionally, the task that was used, the WCST, was not strongly structured, but required the participants to develop their own strategies and to process feedback adequately.

The WCST is a fairly complex task. The advantage of using this task is that it has been used in many studies and clinical settings to examine executive control (Heaton, 1981). Furthermore, there are many

neuropsychological studies that directly show that this task yields activation of brain structures that are deemed to subserve the translation of goals into action (Barcelo et al., 2000; Duncan & Owen, 2000).

The design of this study was comprehensive, which hopefully allows one to gain a clearer understanding of the relationship between fatigue, brain injury and neuropsychological functions. Four different groups of participants were employed, including fatigue with brain injury, fatigue without brain injury, no fatigue with brain injury and no fatigue without brain injury.

Lastly, there are only a few studies that have explicitly investigated the effects of mental fatigue from an executive control perspective (van der Linden, Frese & Meijman, 2003). Many studies have reported the complaint of fatigue after traumatic brain injury, regardless of severity. However, few studies have investigated the mechanisms and implications of fatigue on cognitive functioning (Belmont et al., 2006). This investigation adds to and fills in gaps in the current knowledge in these areas.

Limitations of this Study and Suggestions for Future Research

This study utilised fairly small sample sizes. There were 15 participants in each of the 4 groups. Future research may be improved by using larger sample sizes in order to increase the power of the investigation (Howell, 2004). The trends that were evident in this research may become significant when the sample sizes are increased.

Both TBI and non-TBI individuals were assessed in the morning hours of the day and all participants completed the Digit Span Test at the beginning of the battery. Importantly, both groups performed

equally on this test. This implies that the clinical interview, that the TBI participants were subjected to, prior to the assessment did not bias or disadvantage the group on this measure and so, is unlikely to have affected overall results. Additionally, the non-TBI participants were required to provide demographic data – they were also subjected to a short interview prior to the assessment. Nevertheless, it should be acknowledged that it is plausible that the TBI participants experienced fatigue as a result of the longer interview and thus, were somewhat disadvantaged from the beginning. Furthermore, it is possible that as a result of this, their performance deteriorated further after two hours of testing. Another consideration is that, even though the testing was conducted in the morning, it was impossible to control what they had done prior to the assessment and how well they had slept the night before. Unfortunately, these factors are limitations of the study.

This study was restricted to an examination of moderate and severe TBI participants, with no emphasis being placed on individuals with mild head injuries. Future investigations should include participants with mild TBI in order to better understand the mechanisms and implications of fatigue in this group of people.

Although the current study provides some insight into the cognitive processes of performance under fatigue, there were also some limitations. The first relates to the tasks that were used. The WCST is a relatively complex task in which different cognitive deficits can lead to similar manifestations on the tasks (van der Linden, Frese & Meijman, 2003). Future studies may need to aim at a more direct assessment of the processes that are assumed to underlie loss of flexibility under fatigue.

This study did not investigate the role that motivation plays in cognitive tasks under fatigue. Executive control strongly overlaps with motivation in the sense that adequate control of behaviour is only exerted when some importance is assigned to task goals (Monsell & Driver, 2000). For example, people with impaired executive control seem to lack the 'drive' to engage in self-directed behaviour and to initiate actions (Duncan et al., 1996). Such lack of drive or action initiation is also typical for fatigued people (Meijman, 2000). For this reason, future research should investigate the role of motivation in cognition under fatigued conditions.

In previous research, van der Linden, Frese and Meijman (2003) noted that fatigued participants showed a trend towards an increased number of non-perseverative errors compared to non-fatigued participants, the results of that research showed that perseverative errors were the most reliable effects of fatigue, whereas non-perseverative errors were mainly linked to decreased motivation and increased anger. Emotional reactions to the WCST were not examined in this investigation. This could be further researched in the future, in a study that controls for negative emotional reactions to the task, which could affect performance on the task.

This study did not examine the extent to which fatigued participants were aware of the inappropriateness of their actions during perseveration; it was assumed that they perceived the feedback after a sorting attempt. Thus, even the fatigued TBI participants must have noticed that their sorting actions had not been successful; nevertheless, they evidenced perseveration. Future research could examine the insight of TBI individuals into their performance.

Future research could investigate the differential effects of neurological disease or damage known to influence executive control on WCST performance, including perseveration. Particularly, there are theories on the biological substrates of executive control that state that dopamine plays a major role in the activation (stability) of goal representations (Braver, Barch, Keys, Carter, Cohen, Kaye, et al., 2001). Moreover, dopamine activity has been associated with intrinsic motivation (Tucker & Williamson, 1984). Both of these concepts are strongly related to mental fatigue.

It is generally known that coffee intake, which enhances dopamine release, reduces both the subjective and objective effects of mental fatigue (Lorist, 1998). This idea poses direction for future studies on the relationship between mental fatigue and executive control.

Post-TBI endocrine disorders are frequent among patients, but most of the time are unrecognised as their manifestations are unspecific. Post-TBI endocrine disorders may be indirectly associated with fatigue (Popovic, 2005). Endocrine dysfunction may be a causative factor that was not examined in this study, but that should be investigated in future research.

Conclusions

The results of the current study indicate that individuals with TBI perform more poorly on neuropsychological measures of executive functioning than individuals with no history of head injury. These individuals evidence reduced inductive reasoning and conceptual abilities, as well as increased perseveration and distractibility compared to healthy individuals. This finding has the implication that

TBI individuals will not be able to compensate as efficiently for affected cognitive functions as healthy individuals when they are fatigued.

In line with expectations, trends showed that fatigue resulted in reduced inductive reasoning capacities for both TBI and healthy participants. In daily life, not only TBI individuals, but also healthy individuals, evidence reduced propensity towards analytical thinking when fatigued. This was echoed in the results of this study. Fatigue was also shown to result in greater levels of perseveration in the TBI group. This implies that the level of exerted executive control was reduced under fatigue, that goal activation was reduced under fatigue and that there was reduced integration of feedback under fatigued conditions. Perseveration appears to be a reliable effect of fatigue in TBI individuals.

In this study, trends showed that fatigue resulted in reduced attentional capacity in both TBI and healthy individuals. This has implications for the ability of fatigued people to compensate for reduced cognitive functioning. Furthermore, these individuals would have to make greater effort to sustain their attention when fatigued, in line with van Zomeren, Brouwer and Deelman's (1984) coping hypothesis.

In contrast to expectations, fatigue negatively impacted the ability to hold information active in mind, which is an automatic cognitive process, in both TBI and healthy individuals. Thus, fatigue appears to affect global cognitive functions, and not only the cognitive processes of executive control.

Despite the limitations of this investigation, this study supports the view that compromised executive control underlies behavioural manifestations of mental fatigue. There are several studies showing that fatigue seems to affect high-level cognitive processes (Hockey, 1997; Holding, 1983; Sanders, 1998).

This study approaches fatigue from an executive control perspective. Such a perspective has important implications. Compromised executive control under fatigue does not imply that certain basic cognitive processes can no longer be executed at all. It does not imply that cognitive processes are fundamentally changed under fatigue. From a goal-activation perspective, compromised executive control under fatigue implies a reduced probability that actions will be guided by task goals or by changing task context (Braver et al., 2001). Subsequently, there will be an increased tendency for more automatic regulatory processes to guide action selection, even when this is inappropriate. Lapses in the exertion of executive control may be responsible for the typical slips of action and intrusion errors that are often found in fatigued people (Hockey, 1997; Holding, 1983; Sanders, 1998).

This study also supports the view that fatigue impacts automatic cognitive processes, such as the ability to hold information active in mind, in addition to it's effects on executive control. The inference that can be made from this research is that fatigue impacts on global cognitive functioning, not only on executive control. The fact that more automatic functions are affected brings to the fore the difficulties that fatigued individuals face; their ability to compensate for a reduction in executive control is hampered.

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Appendices

Appendix 1:

Glasgow Coma Scale (GCS)

Subscale	Criteria	Score
Eyes Opening:	Spontaneous	4
	To command	3
	To pain	2
	None	1
Best Verbal Response:	Oriented	5
	Confused/disoriented	4
	Words only	3
	Sounds only	2
	None	1
Best Motor Response:	Obeys commands	6
	Localises pain	5
	Flexion/withdrawal to pain	4
	Abnormal flexion to pain	3
	Extension to pain	2
	None	1

Appendix 2:

Loss of Consciousness (LOC)

Severity of TBI	Finding
Mild	Mental status change or LOC < 30 minutes
Moderate	Mental status change or LOC 30 minutes – 6 hours
Severe	Mental status change or LOC > 6 hours

Appendix 3:

Neuropsychological Battery

Fatigued Group	Non-Fatigued Group
Forward Digit Span Test	Forward Digit Span Test
UCLA-AVLT	VAS-F
Story Memory Test	WCST
COWA	UCLA-AVLT
Trails A	Story Memory Test
Trails B	COWA
Symbol Digit Substitution	Trails A
Taylor Complex Figure	Trails B
WAIS-R Arithmetic Test	Symbol Digit Substitution
WAIS-R Block Design Test	Taylor Complex Figure
Stroop Colour-Word Interference Test	WAIS-R Arithmetic Test
VAS-F	WAIS-R Block Design Test
WCST	Stroop Colour-Word Interference Test
Forward Digit Span	Forward Digit Span

Appendix 4:

Semi-Structured Clinical Interview

Medical History

- Did you have any significant illnesses or injuries prior to the accident in question?
- Have you ever been diagnosed with any endocrine disorder, diabetes, hypercholesterolemia or hypertension?
- Have you ever been diagnosed with any developmental, psychological or psychiatric disorder?
- Is there anything else of significance in your medical history, including any previous trauma or surgeries etc?

Social Circumstances

- Where do you live and with whom?
- Are you single/married?
- Do you have any children?
- If so, how many?
- What are their ages?

Educational History

- Did you fail any years at school?
- What was your final level of education?

- If not Matric, why?
- Did you complete any tertiary qualification?

Employment History

- Where were you working at the time of the accident?
- How long had you been employed in that position?
- How long were you off work after the accident?
- Are you currently employed?
- Did you return to the same position?
- Do you have the same responsibilities as prior to the accident?

Circumstances of the MVA

- Do you recall any of the events surrounding the accident?
- What is your last memory prior to the accident?
- What is your first memory after accident and how long after the accident was this?
- Do you remember your time spent in hospital?
- Were you recognising people at this time?
- How long were you unconscious?
- What was your mental state like after discharge?

Current Complaints due to MVA

- What problems do you experience that you regard as being caused by the accident?

Medication

- Are you currently taking any prescription medication?
- If so, what?

Headaches

- Were headaches a problem prior to the accident?
- Are headaches a problem post-injury?
- Post-injury, how many times a week do you suffer from headaches?
- Where do the headaches originate?
- Are the headaches responsive to over-the-counter analgesics?

Epilepsy

- Is there a family history of epilepsy?
- Have you developed epilepsy following the accident?
- How many episodes have you experienced and/or how often do you experience them?
- If so, what treatment are you on?
- Has an EEG been done?

Sleep and Appetite

- Has there been a change in sleeping pattern?
- Do you experience nightmares?
- Has there been a change in appetite?
- Have you gained/lost weight?
- Have your food preferences changed?

Activities of Daily Living

- Do you cope adequately with all basic activities of daily living?
- Do you contribute to household chores?

Sensory Functions

Do you have any complaints regarding:

- Vision, specifically any double vision or blurring?
- Hearing, specifically any tinnitus or hearing loss?
- Olfaction, specifically can you smell your food?
- Touch, specifically any pins-and-needles or numbness anywhere on your body?
- Taste, specifically can you taste your food?

Motor Functions

- Do you experience any difficulty with motor functions?
- Are walking, bending and sitting done normally?
- Are there coordination problems?

- Are there complaints with regard to your balance?
- Can you pick up heavy objects?

Cognitive Problems

- Do you experience any difficulties with long-term memory?
- Do you experience any difficulties with short-term memory?
- Do you misplace any personal belongings and/or forget what people tell you?
- Do you experience any difficulties with concentration?
- Do you experience any difficulties with attention?
- Are you able to track movies and conversations?
- Has there been a change in your voice?
- Do you slur or stutter?
- Is dysnomia a problem?
- Do you struggle to think of the correct word to use in conversation?
- Do you experience any problems with the comprehension of language?
- Do you understand all of what is said to you?
- Are you able to solve everyday problems, this may include resolving a dispute or knowing what to do when an appliance breaks?
- Are you able to calculate small change?

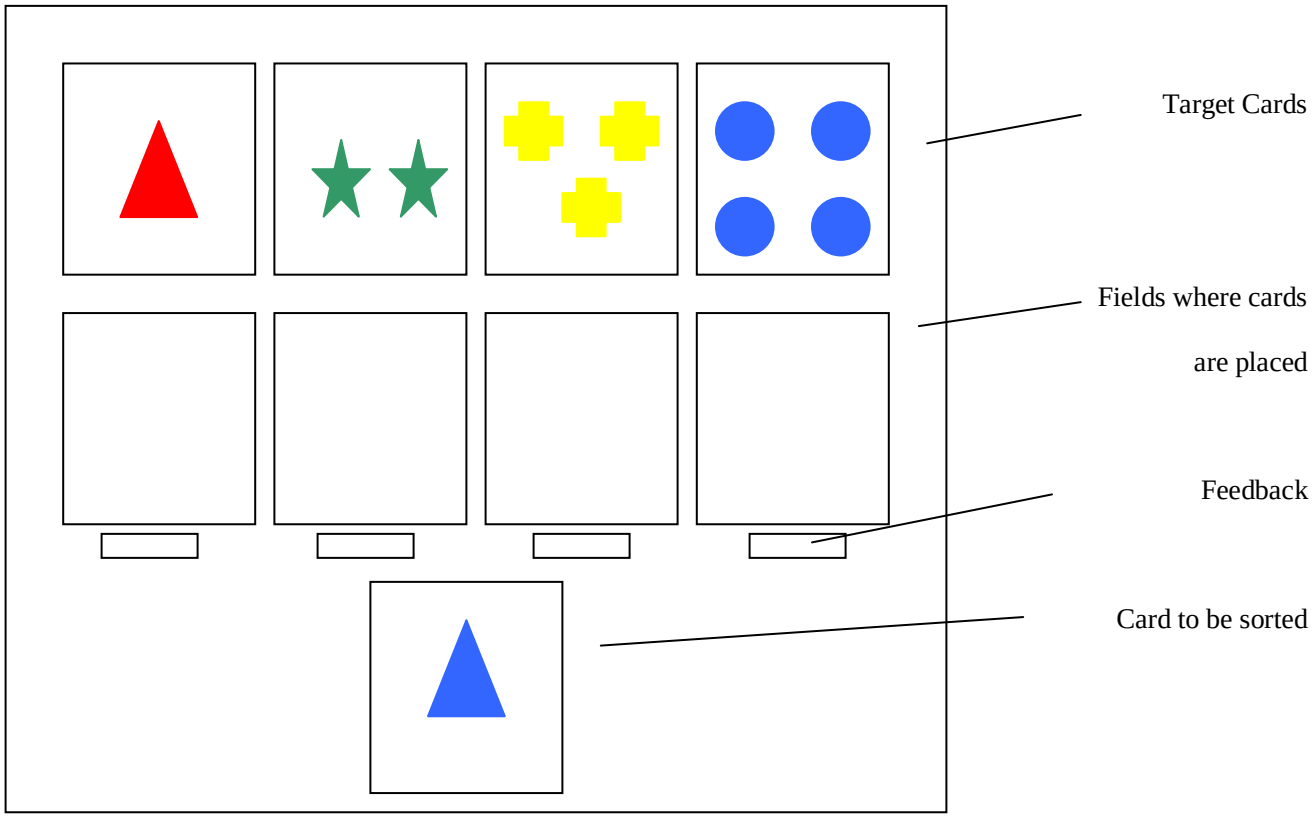
Emotional Problems

- Are you more easily irritated?
- Are you more aggressive?

- Are you able to control your temper?
- Have your friendships changed?
- Has the number of friends changed?
- Do you socialise more or less often?
- Do you suffer from anxiety?
- Would you consider yourself to be depressed?
- Has your level of motivation changed?
- Do you procrastinate?

Appendix 5:

Diagram of Layout of WCST on Computer Screen



Appendix 6:

The Wisconsin Card Sorting Test Scorecard

	Raw Score	Percent	*z*-Score	Mean	SD
Accuracy					
Categories Shifted		—		5.4	1.3
Correct Responses			—	—	—
Incorrect Responses				24.9	19.4
Perseveration					
Perseverative Responses				15.6	11.5
Perseverative Errors				12.6	10.2
Non-perseverative Errors				12.4	11.3
Conceptual Ability					
Moves to First Category Shift		—		13.4	10.6
Conceptual Level Responses				69.2	17.3
Set Maintenance and Learning					
Failures to Maintain Set		—		0.8	1.3
Learning to Learn		—		-2.9	5.8
Miscellaneous					
First Unambiguous Sort		—	—	—	—
Cards Sorted			—	128	—

Appendix 7:

The Forward Digit Span Test

Number of Digits	Trial 1	Trial 2	Trial 3
3	5 2 7	3 7 9	4 2 8
4	3 8 1 9	1 3 9 4	5 9 8 6
5	6 3 7 5 1	8 2 4 9 7	1 3 6 2 9
6	3 1 9 5 2 8	7 9 5 1 4 8	3 9 7 6 2 4
7	5 9 7 2 4 1 6	4 6 2 8 1 9 5	3 6 2 9 1 8 5
8	9 5 1 4 2 7 3 6	5 3 1 6 2 4 9 7	6 8 2 4 5 1 9 3
9	3 6 9 2 5 8 1 4 7	7 5 3 6 8 9 2 4 1	1 5 6 3 9 2 8 4 7

Appendix 8:

Visual Analogue Scale for Fatigue (VAS-F)

I am trying to find out about your level of energy. There are 18 items that I would like you to respond to. This should only take 1 minute of your time to do. Thank you.

DIRECTIONS: You are asked to place an 'X' through these lines to indicate how you are feeling RIGHT NOW. For example, suppose you had not eaten since yesterday. Where would you put the 'X' on the line below?

Not at all hungry _____ Extremely hungry

You would probably put the 'X' closer to the "extremely hungry" end of the line. This is where I would put it:

Not at all hungry _____ Extremely hungry

NOW PLEASE COMPLETE THE FOLLOWING ITEMS

Not at all tired _____ Extremely tired

Not at all sleepy	_____	Extremely sleepy
Not at all drowsy	_____	Extremely drowsy
Not at all fatigued	_____	Extremely fatigued
Not at all worn out	_____	Extremely worn out
Not at all energetic	_____	Extremely energetic
Not at all active	_____	Extremely active
Not at all vigorous	_____	Extremely vigorous

Not at all efficient	_____	Extremely efficient
Not at all lively	_____	Extremely lively
Not at all bushed	_____	Extremely bushed
Not at all exhausted	_____	Extremely exhausted
Keeping my eyes open is no effort at all	_____	Keeping my eyes open is a tremendous chore
Moving my body is no effort at all	_____	Moving my body is a tremendous chore

Concentrating is no effort at all ——— Concentrating is a tremendous chore

Carrying on a conversation is no effort at all ——— Carrying on a conversation is a tremendous chore

I have absolutely no desire to close my eyes ——— I have a tremendous desire to close my eyes

I have absolutely no desire to lie down ——— I have a tremendous desire to lie down

Items 1-5 and 11-18 belong to the fatigue subscale. Items 6-10 belong to the energy subscale.

Appendix 9:

Permission to use test data

Digby S. Ormond-Brown MA *(cum laude)*
Clinical Neuropsychologist
HPCSA Registered Psychologist (Clinical & Research)

Consulting Rooms:
Netcare Rehabilitation Hospital
Suite 2-44
Canary Road
Auckland Park
Johannesburg

Telephone:
011 489-1320
Fax:
011 482-3201
E-mail:
practice@ormond.co.za
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Postal Address:
PO Box 10
Melville 2109
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Associates:
Keentseng T Russell
BSc Hons (Psych), BSc Hons (Rehab) cum laude
Jessica Dawn Fry
BSc Hons (Psych) cum laude
Neo Batenegi
BSc Hons (Psych)

Administration:
Jennifer Ormond-Brown

Registration #'s:
HPCSA: PS0029742

13 August 2008

To whom it may concern,

Re: Permission to use test data

This letter serves as permission for Ms Jessica Dawn Fry (student number 0301352X) to use the psychometric test data, that are obtained during the standard neuropsychological evaluations that take place in this practice, for research purposes. Furthermore, the individuals were aware at the time of testing that their test data may be used for research purposes. These individuals were required to sign consent forms prior to testing giving permission for their test data to be used for research purposes.

Yours sincerely,



Digby Ormond-Brown

Appendix 10:

Non-TBI Group Subject Information Sheet



School of Human and Community Development
Private Bag 3, Wits 2050, Johannesburg, South Africa
Tel: (011) 717-4500 Fax: (011) 717-4559
Email: jessica.fry@hotmail.com

My name is Jessica Fry, and I am conducting research for the purposes of obtaining a Masters Degree at the University of the Witwatersrand. I want to look at how fatigue affects performance on different neuropsychological measures. I would like to invite you to participate in this study.

If you decide to take part in the study, you will be required to complete approximately two hours of cognitive tasks. These tasks assess different areas of neuropsychological functioning. I will administer the tasks, at a time that is convenient for you at the offices of Digby Ormond-Brown at the Netcare Rehabilitation Hospital in Auckland Park. Participation is voluntary, and no one will be advantaged or disadvantaged in any way for choosing to participate or not participate in the study. In other words, there are no risks or benefits for participating in the study. You may choose to withdraw from the study at any point.

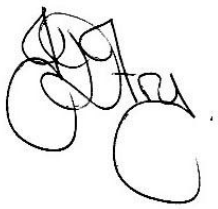
All of your responses will be kept confidential. No information that could identify you will be included in my research report; confidentiality in this respect is guaranteed. Furthermore, all results will be coded,

so that names do not appear. The results of the tasks will be processed by myself. Results of the study will be reported in a research report and may later be reported in a journal.

If you choose to participate in the study please sign the consent form. If you have any queries, I can be contacted telephonically at 082 376 2980 or via e-mail at jessica.fry@hotmail.com.

Your participation in this study would be greatly appreciated. This research will contribute to a larger body of knowledge on fatigue and cognitive performance.

Kind Regards,



Jessica Dawn Fry.

Appendix 11:

Non-TBI Consent Form

I, _____, consent to partaking in the tasks, which will be administered to me by Jessica Fry for her study on the fatigue on neuropsychological functioning. I understand that:

- Participation in this study is voluntary.
- There are no risks or benefits to participating in the study.
- I may withdraw from the study at any time.
- No information that may identify me will be included in the research report, and my responses will remain confidential.

Signed_____ Date_____

Appendix 12:

Ethics Clearance Certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

HUMAN RESEARCH ETHICS COMMITTEE (SCHOOL OF HUMAN & COMMUNITY DEVELOPMENT

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: MDISS/08/001 IH**
PROJECT TITLE:	Traumatic brain injury and mental fatigue: Effects on Executive Control.
INVESTIGATORS	Fry Jessica
DEPARTMENT	Psychology
DATE CONSIDERED	08/09/08
DECISION OF COMMITTEE*	Approved

This ethical clearance is valid for 2 years and may be renewed upon application

DATE: 10 September 2008

CHAIRPERSON _____
(Professor C. Cockcroft)

cc Supervisor: Mrs Enid Schutte
Psychology

DECLARATION OF INVESTIGATOR (S)

To be completed in duplicate and **one copy** returned to the Secretary, Room 100015, 10th floor, Senate House, University.

I/we fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure be contemplated from the research procedure, as approved, I/we undertake to submit a revised protocol to the Committee.

This ethical clearance will expire on 31 December 2009

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix 13:

Assessment of Residuals of Models for Normality

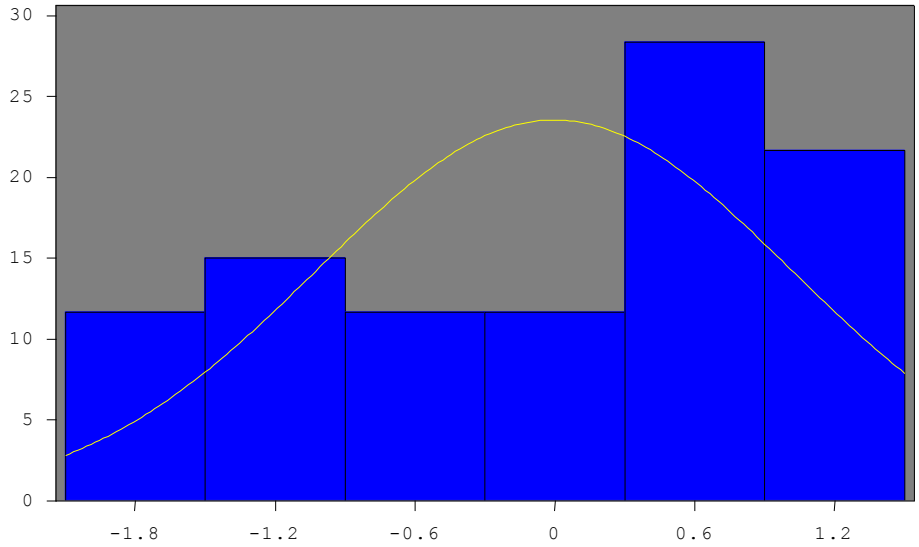


Figure 6. A Histogram Showing the Distribution of the Residual Values for the Dependent Variable of Fatigue

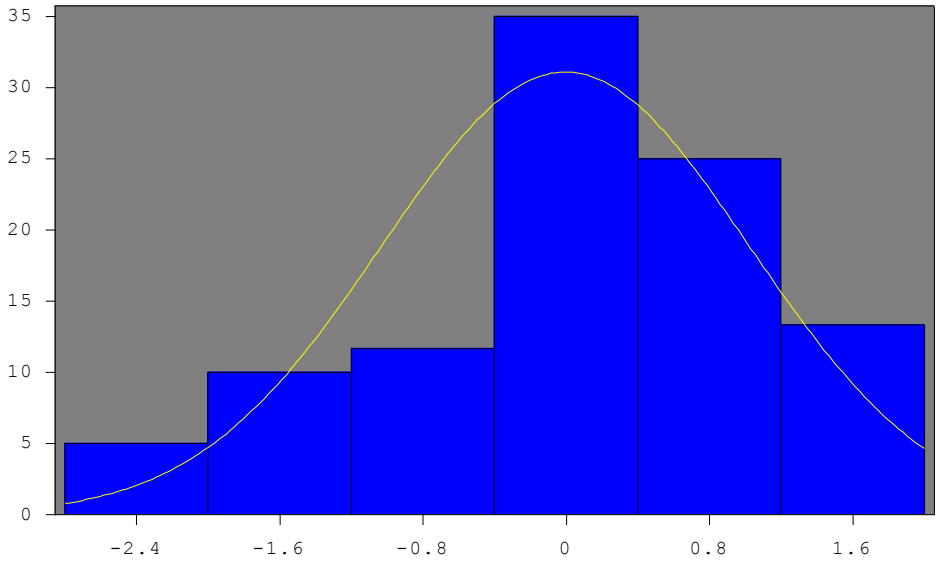


Figure 7. A Histogram Showing the Distribution of the Residual Values for the Dependent Variable of Number of Sorts

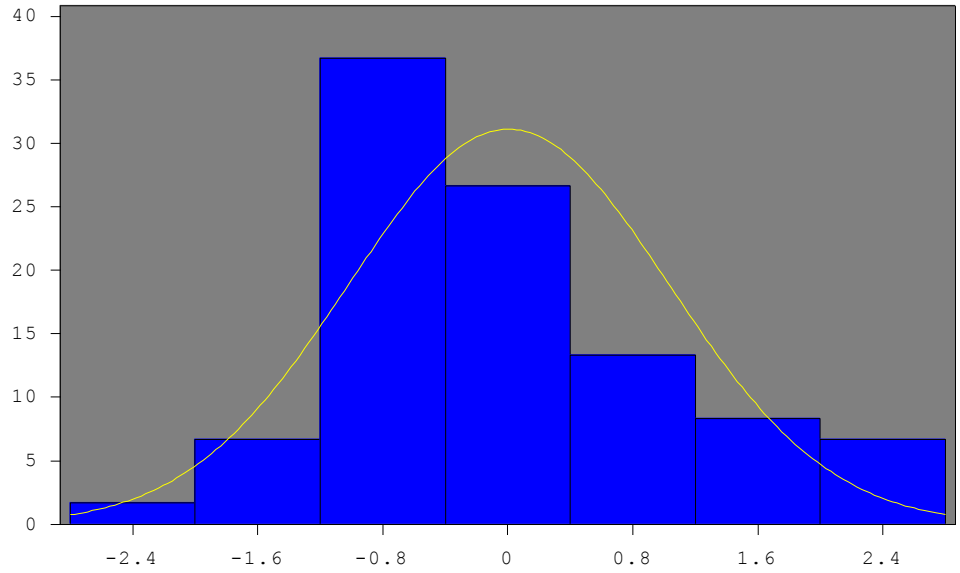


Figure 8. A Histogram Showing the Distribution of the Residual Values for the Dependent Variable of Percent Perseveration

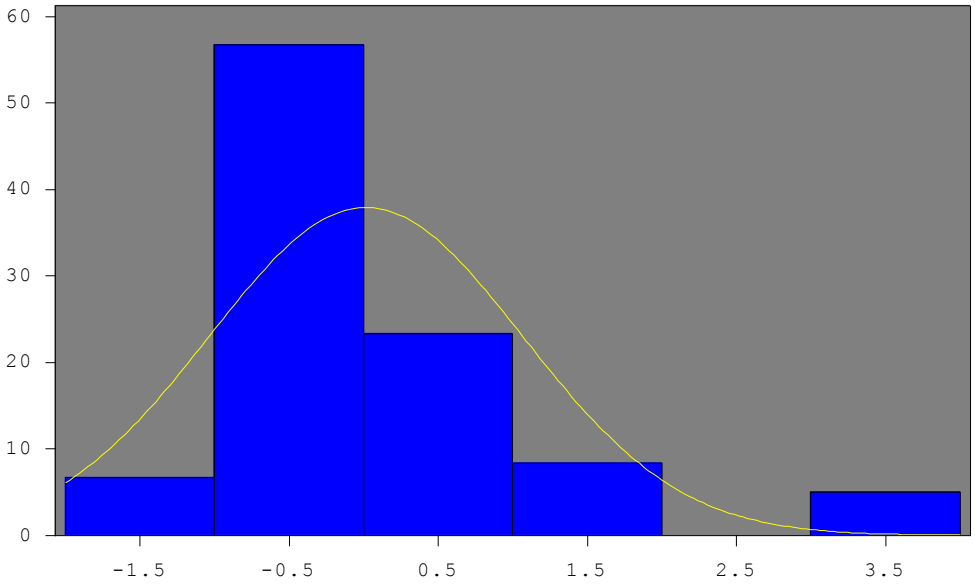


Figure 9. A Histogram Showing the Distribution of the Residual Values for the Dependent Variable of Percent Non-Perseverative Errors

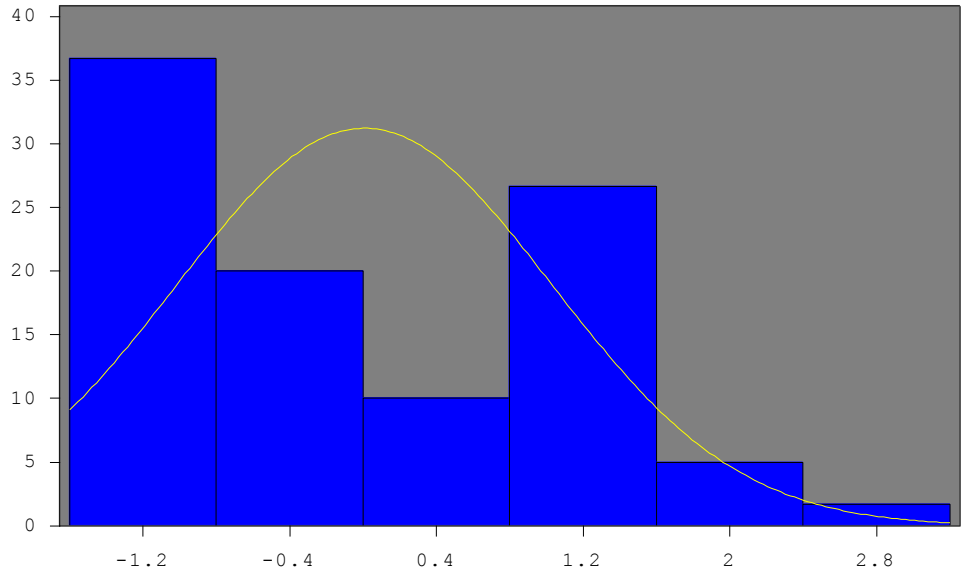


Figure 10. A Histogram Showing the Distribution of the Residual Values for the Dependent Variable of Number of Failures to Maintain Set

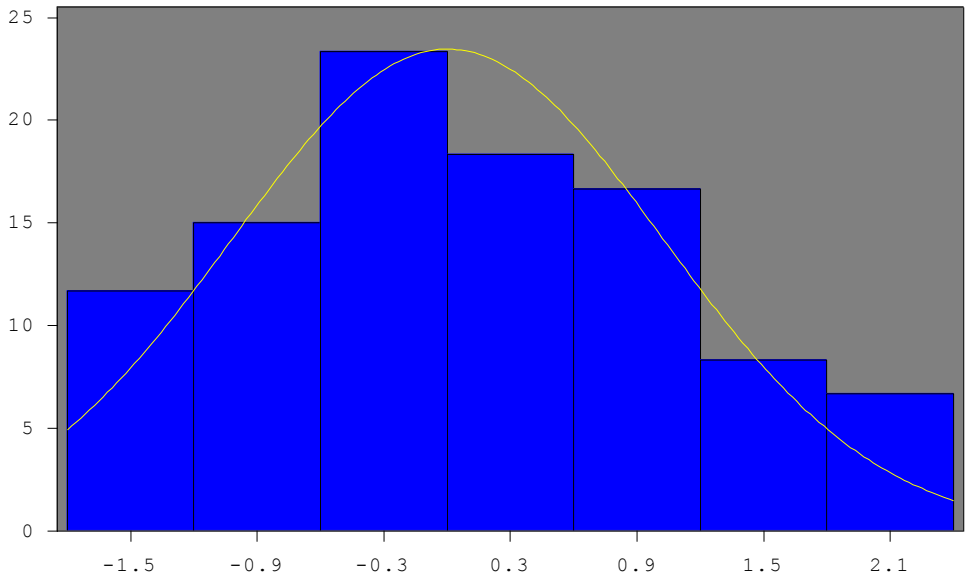


Figure 11. A Histogram Showing the Distribution of the Residual Values for the Dependent Variable of Pre-Manipulation Digits Forward

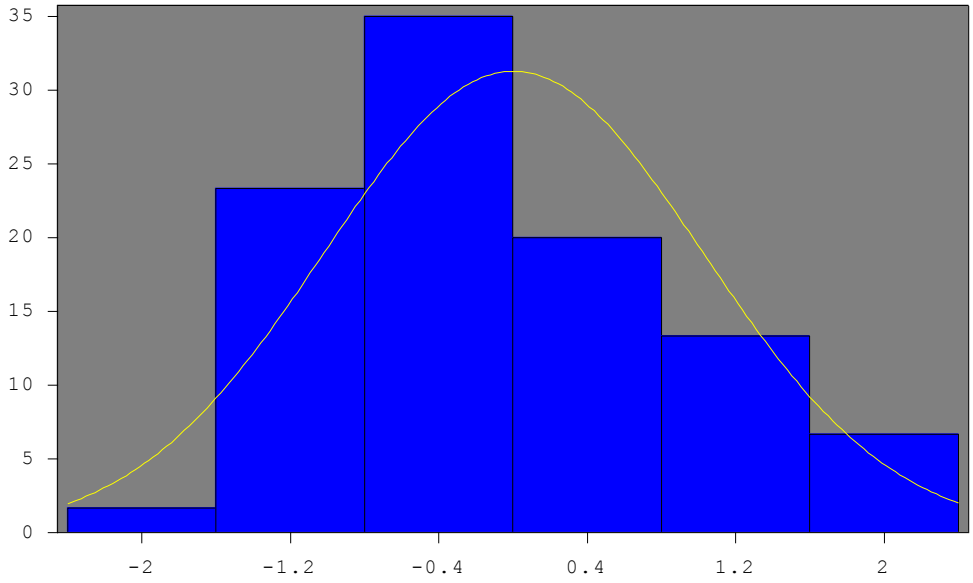


Figure 12. A Histogram Showing the Distribution of the Residual Values for the Dependent Variable of Post-Manipulation Digits Forward