A Cognitive Profile of South African Children with Traumatic Brain Injury

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COMPULSORY DECLARATION

This work has not been previously submitted in whole, or in part, for the award of any degree. It is my own work. Each significant contribution to, and quotation in, this dissertation from the work, or works, of other people has been attributed, and has been cited and referenced.

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Abstract

Research conducted on pediatric populations have shown that an event such as a traumatic brain injury (TBI) experienced in childhood can lead to persistent neuropsychological deficits months, even years post-injury. However, there still exists a dearth of research on pediatric TBI (pTBI), more so in developing countries like South Africa as most pediatric studies have been conducted on Western populations. This situation underlines the need for more research in the field of pTBI. The current study therefore aimed to fill the gap in literature found on pTBI in South Africa. Furthermore, it aimed to generate an updated profile of neuropsychological functioning in South African children with TBI with the hopes that such a profile will ultimately inform comprehensive neuropsychological rehabilitation and school programs with realistic expectations, both geared towards facilitating the child's adaptive functioning in his/her environment. The final aim of the current research was to lay the groundwork for development of a battery of culturally-appropriate measures that is sensitive to neuropsychological functioning within the South African context. Such a battery will benefit both clinicians and researchers by putting at their disposal easily accessible neuropsychological measures specifically geared towards the identification of TBI in South African children.

The sample included three groups, consisting of 12 children with mild TBI, 12 children with moderate-severe TBI, and 24 age-, sex-, and SES-matched healthy controls. Cognitive functioning in the domains of general intellectual functioning, attention, memory, and executive abilities were compared across these groups by means of ANOVA and multiple hierarchical regression analyses. Results showed that the moderate-severe TBI participants performed significantly worse than controls in the measures of verbal IQ, selective/focused attention, inhibition, and cognitive flexibility. Furthermore, the children with moderate-severe TBI performed worse than those with mild TBI on measures of selective/focused attention, inhibition, and cognitive flexibility. No significant differences were found between the mild TBI and control participants. South African children with moderate-severe TBI appear to experience impairment in verbal knowledge and semantic abstract reasoning abilities, attention and concentration, the ability to inhibit automatic responses, and the production of novel, unique designs using flexible thought processes. Finally, the results indicated that the WASI Vocabulary and Similarities subtests and CMS Numbers forward subtest, specifically, are reliable measures for assessing neuropsychological functioning in South African children with TBI.

Keywords: neuropsychological functioning; pTBI; comprehensive neuropsychological rehabilitation; culturally-appropriate measures; verbal IQ; selective/focused attention; inhibition; cognitive functioning

Introduction

Very little South African research has been done in the area of cognitive functioning in pediatric traumatic brain injury (pTBI). The bulk of such research originates from developed-world nations such as the United Kingdom (Hawley, 2003; Hawley, Ward, Magnay, & Long, 2002; Webb, Rose, Johnson, & Atree, 1996), Australia (Anderson, Fenwick, Manly, & Robertson, 1998; Catroppa & Anderson, 2003, 2005; Willmott, Anderson, & Anderson, 2000), and the United States (Ewing-Cobbs et al., 1998; Levin et al., 2004; Roberts, Verduyn, Manshadi, & Hines, 1996; Taylor & Alden, 1997; Yeates et al., 2002). Even internationally, however, neuropsychological outcome has been less thoroughly studied in pediatric than in adult populations (Baxter, Cohen, & Ylvisaker, 1995). The current study attempted to fill the gap in literature on neuropsychological outcome in pediatric TBI in South Africa.

More specifically, the aim of the present study was to generate an updated and comprehensive cognitive profile of children with TBI, in the hope that such a profile will ultimately inform (a) effective neuropsychological rehabilitation programs, and (b) school programs with realistic expectations, both geared towards facilitating the child's adaptive functioning in his/her environment (Baxter, Cohen, & Ylvisaker, 1995; Tranel & Eslinger, 2000). Furthermore, this study serves as an initial step in the development of a battery of standardised neuropsychological measures that is sensitive to the unique South African cultural context and that has particular utility in both clinical and research settings.

Plasticity versus Vulnerability in the Developing Brain

Studies conducted on adult samples provide a good basis for understanding the particular profile of cognitive dysfunction following a TBI. However, factors such as age and developmental stage at which the injury occurred exert significant influence on cognitive outcomes. For this reason, we cannot simply extrapolate from adult populations how TBI will present in children (Ewing-Cobbs, Fletcher, & Levin, 1995; Satz, 2001).

The two main debates around which pediatric TBI can be understood centers on whether the young brain is plastic and therefore associated with fewer negative outcomes, or whether the immature cerebral regions are more vulnerable to disruption following TBI (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2005; Verger et al., 2000).

Developmental plasticity. The role of age at injury in determining outcome is a contentious issue in the pTBI literature. A number of early studies provided support for the plasticity theory (e.g., the Kennard principle; Zillmer, Spiers, & Culbertson, 2008) which states that it is better to have a brain injury at an early age because the brain is still malleable or "plastic" (Verger et al., 2000). Following this principle, a more positive prognosis is associated with a younger age at injury

with recovery proceeding on the basis of either reorganization or restitution. The former states that non-injured regions assume the functions of injured regions, whereas the latter posits that damaged tissue and previously disrupted functions are restored, leading to reactivation of neural pathways and restoration of functions (Chapman & McKinnon, 2000).

Reorganisation of function. In the substitution or reorganization of functions, the brain is characterized by plasticity through either of two mechanisms: *anatomical reorganisation* or *behavioural compensation* (Kolb & Whishaw, 1998; Raymont & Grafman, 2006). The mechanism of anatomical reorganization rests on the fact that the immature central nervous system (CNS) of the young child features large and unspecialized cerebral regions. Due to the unspecialized nature of the young brain, cognitive functions are not yet fixed to specific brain regions allowing for transference of functions to healthy tissue in the event of brain insult. When reorganization is accomplished through behavioural compensation, the child either learns new strategies for cognitive functions or uses external strategies to minimize cognitive impairment. For example, a child with memory difficulty may use a diary to assist in learning new information (Anderson, Northam, Hendy, & Wrennal, 2001).

Restitution of function. A picture of generalized impairment follows in the first weeks after TBI. This stage is followed by rapid recovery of spared cerebral tissue. Such recovery is only possible, however, when function has been disrupted but not entirely destroyed. Rapid recovery after a TBI is made possible through particular cerebral mechanisms one of which is *diaschisis*. This is the initial stage of recovery in which activity in brain areas far from the original site of injury is suppressed (Zillmer et al., 2008).

In addition, *regeneration* has been proposed as a process of recovery where neurons, axons, and terminals regrow so that previous neuronal connections are reestablished. With axonal sprouting there is a regrowth of neurons that were only partially damaged may resprout. Collateral sprouting may occur with the resprouting of undamaged nearby neurons (Kolb & Whishaw, 1998; Raymont & Grafman, 2006; Zillmer et al., 2008). This process reportedly occurs in the early stages following brain insult and is usually complete within weeks.

A final process that might underlie restitution of function is that of *denervation supersensitivity*. This mechanism operates on the basis of post-lesion pathways being stimulated in damaged cerebral regions, leading to restoration of normal functioning. Stimulation of lesion pathways is made possible through postsynaptic processes becoming supersensitive to neurotransmitter substances that seep from pre-lesion neurons (Kolb & Whishaw, 1998; Zillmer et al., 2008).

Early vulnerability. Early vulnerability theories, in contrast to plasticity theories, state that the developing brain contains a number of functions that are still in the process of emerging, and

that disruption of these processes will lead to the poorest cognitive, behavioural, and affective outcomes. Otherwise stated, brain insult early in life may have *more* negative implications than later injury because some aspects of cognitive development depend on particular brain structures being intact and without insult at certain stages of development (Anderson, Morse, Catroppa, Haritou, & Rosenfeld, 2004; Benz, Ritz, & Kiesow, 1999; Chapman & McKinnon, 2002; Dennis & Levin, 2004; Willmott, Anderson, & Anderson, 2000). A child who has experienced early brain trauma may therefore not adequately develop some or many cognitive abilities (e.g., executive functions such as planning and decision-making) at the time they normally emerge and stabilize (e.g., early adolescence; Sohlberg & Mateer, 2001; Tranel & Eslinger, 2000).

Early vulnerability, therefore, suggests that children who have sustained early TBIs can "grow into their deficits": the TBI may have no observed consequences until the skills subserved by the damaged brain region would emerge in the normal course of cognitive development. This is what Brenner et al. (2007) term the "latent" sequelae of TBI: Recovery may appear complete, only for deficits to emerge several months to several years post-injury.

Support for early vulnerability theories comes from various studies showing that poorer outcomes are associated with a younger age at injury (Catroppa & Anderson, 2002; Ewing-Cobbs et al., 1998; Verger et al., 2000). For instance, several studies show that adolescents who sustained TBI at an early age typically show deficits in executive functions and in various attentional abilities (Anderson & Pentland, 1998; Brenner et al., 2007; Fenwick & Anderson, 1999).

New perspectives on TBI. Current thinking holds that recovery from early-onset brain injury should be understood within a context of both plasticity and vulnerability (Dennis & Levin, 2004). Specifically, contemporary researchers hold the view that within the young brain there is plasticity supporting recovery (i.e., recovery can occur using mechanisms of restitution and reorganization) as well as plasticity supporting development (i.e., the immature brain is able to acquire new skills). Both of these processes play a role in positive long-term outcomes associated with brain injury at a young age. However, it is important not to lose sight of the fact that plasticity and vulnerability coexist, and that both are influencing factors in the child's recovery process (Chapman & McKinnon, 2000).

Traumatic Brain Injury

The term "traumatic brain injury" (TBI) refers to trauma to the brain that often results in unconsciousness and is of such severity that admission to a hospital is necessary (De Villiers, Jacobs, Parry, & Botha, 1984; Haller, 1983). A TBI is typically the result of wound or blunt force to the head that is capable of leading to altered consciousness and that could possibly result in functional impairment (Brooks, 1995).

Prevalence of TBI. TBI is a serious public health concern. It is a major cause of death and disability in children, a situation that necessitates both rigorous research and more comprehensive rehabilitation programmes (Anderson & Yeates, 2007; Bruns & Hauser, 2003; Hawley, Ward, Long, Owen, & Magnay, 2003; Lalloo & van As, 2004; Maegele et al., 2007; McKinlay et al., 2007).

In the United States, incidence reports suggest that as many as 180-250 per 100 000 children sustain a TBI in any one year (Anderson et al., 2001; Bruns & Hauser, 2003). A more recent report from Centers for Disease Control and Prevention, National Center for Injury Prevention and Control (Faul, Xu, Wald, & Coronado, 2010) indicates that for the period 2002 to 2006, 473 947 emergency department visits related to TBI were made by American children between the ages of 0 and 14 years on an annual basis. Furthermore, a 62% increase in TBI as a result of falls was seen in children aged 14 years and younger for the same period. Hooper et al. (2004) report that as many as 1.5 to 2 million Americans sustain brain trauma in one year; of these 50 000 are fatalities, 230 000 are hospitalized, and 1 million are treated and discharged from hospital emergency wards. Of those who survive, 80 000 will have some level of permanent disability. A UK-based study estimated that 280 per 100 000 children are admitted to hospital due to TBI each year (Hawley et al., 2003).

In South Africa, an estimated 3 000 children younger than age 15 years die, and many more are disabled, each year as a result of TBI (Cywes, 1990). In a retrospective analysis of severe pTBI cases, Semple, Bass, and Peter (1998) found that over a 5-year period, 57 468 children were seen at Red Cross War Memorial Children's Hospital (RXH) in Cape Town. A separate retrospective record-based study at RXH showed that over a third of approximately 94 000 records listed TBI as nature of injury (Lalloo & van As, 2004).

These incidence rates are indicative of the great number of children seen by practitioners each year. This situation highlights the reality of pTBI as a serious health problem both locally and internationally.

Nature of injury. The mechanics underlying TBI are an important factor in providing a clear picture of the repercussions this type of injury could have (Willmott et al., 2000). Within the pediatric population causes of brain trauma are various and usually include motor vehicle accidents (MVAs), falls, blows, missile wounds, and child abuse (Bruns & Hauser, 2003; McKinlay, Grace, Horwood, Fergusson, & McFarlane, 2009). Falls and MVAs account for the majority of all cases of head injury (Hawley et al., 2003; Lalloo & van As, 2004). In addition, MVAs account for more severe head injuries (De Villiers et al., 1984; Semple et al., 1998). TBIs are classified as either 'open' or 'closed', depending on whether the skull was penetrated by a foreign missile or not.

Open head injury. In this type of injury, brain tissue is destroyed in the area surrounding the foreign missile, leading to more localized pathology (Brooks, 1995). Damage depends to a large

extent on the velocity of the foreign object. For instance, a high caliber bullet may cause extensive damage, whereas a bullet with lower velocity may only lead to a small focal lesion. Prognosis for this class of injury is more positive than that for closed head injury, with deficits being more focal in nature and reflecting the linear path of the cerebral lesion.

Closed head injury. In the case of CHI the primary cause of damage is one of blunt impact. It is typically associated with loss of consciousness and diffuse brain damage. Motor vehicle accidents (MVAs) are a common cause of CHI, and are associated with acceleration/deceleration and linear and rotational forces. Essentially, the brain is shaken backward and forward and rotated with the force of the impact, with extensive shearing and tearing of neurons leading to diffuse axonal damage (Bennett & Raymond, 1997; Satz et al., 1997). In addition, the shaking of the brain in the skull cavity leads to multiple injury sites with damage to areas opposite the original location of trauma.

The multifocal pathology characteristic of CHI is usually attributed to four possible mechanisms. Firstly, lesions may form at the site of impact (coup injury). The second type of damage involves changes in intracranial pressure that may lead to lesions in cerebral regions directly opposite to the original site of impact (contrecoup injury). The third type of damage entails the brain moving within the skull cavity, resulting in lesions in the sphenoidal ridge region. This type of injury, also known as sphenoidal injury, leads to damage to the frontal and temporal cerebral lobes. Finally, as a result of movement of the brain, a number of surface lesions are produced by tearing of the veins that leave the upper boundaries of the cerebral hemispheres the movement of the brain (gliding contusions; Brooks, 1995; Richardson, 2000).

As noted above, closed head injuries are associated with poorer functional outcomes as opposed to open head injuries; this poorer prognosis is largely due to the multifocal pathology characteristic of CHI but not OHI (Anderson et al., 2001).

Predictors of outcome following CHI. Neuropsychological outcome is not only affected by the mechanism and severity of injury. Researchers in the field suggest a number of variables that play a significant role in the trajectory of recovery following childhood TBI. Important factors that have been identified include age at injury (AAI), injury severity, premorbid functioning, and psychosocial factors. Each of these will be dealt with in turn below.

Age at injury. It is important to consider that the developmental stage at which a pediatric TBI occurs could have serious adverse effects on the child's development (Anderson et al., 2004; Benz et al., 1999; Ewing-Cobbs et al., 1998; Lord-Maes & Obrzut, 1996; Tranel & Eslinger, 2000; Willmott et al., 2000). A growing body of evidence suggests that age at which TBI occurs is an important indicator of outcome (Anderson et al, 1997, 2000; Ewing-Cobbs et al., 1995; Taylor & Alden, 1997; Tranel & Eslinger, 2000; Ward, Shum, McKinlay, Baker, & Wallace, 2007) with

younger age at injury being predictive of a poorer prognosis (Verger et al., 2000). Semple and colleagues (1998) assessed 102 children between the ages of 0 and 13 years and found that a poorer prognosis was associated with an AAI less than 3 years. Anderson and Moore (1995) found similar results in their study involving 16 children injured from 3.9 to 6.9 years of age. Children who sustained an insult before age 7 performed significantly worse than those injured at the age 7. In the same study, recovery patterns after injury were also associated with AAI, with children injured at an earlier age failing to follow the anticipated acute recovery profile and exhibiting stable neurobehavioural performance from the acute phase to 2 years post-injury. In contrast, children with a later AAI demonstrated a recovery pattern consistent with that for adult TBI, with improvement in performance between acute and follow-up assessments. However, a study of 33 moderately injured children, with AAI ranging from 1 to 12 years, found that this factor was not predictive of outcome and did not predict behavioural symptoms of inattention as indicated by parent reports (Willmot et al., 2000). The authors suggest that these results could be due to the fact that AAI only affects development after a severe TBI.

This pattern of data where younger age at injury is associated with poorer, more persistent neuropsychological performance could be attributed to early vulnerability and a relative lack of myelination of the immature brain (Chapman & McKinnon, 2000; Willmott et al., 2000). This lack of myelination makes the young brain particularly susceptible to shearing and tearing effects of a CHI, making the young child more vulnerable to diffuse trauma and putting him/her at greater risk for long-term cognitive impairment. Furthermore, with a younger age at injury prefrontal cerebral regions are in a rapid state of development. The fact that the prefrontal brain areas are immature and in a state of flux further compound the vulnerability of the young brain as normal development of the skills subsumed by these regions would be interrupted (Anderson et al., 2004; Mandalis Kinsella, Ong, & Anderson, 2007; Tranel & Eslinger, 2000).

Time since injury. The time between when the injury occurred and when test measures are administered is a mediating factor in the trajectory of recovery (Dennis & Levin, 2004; Vargha Khadem, Isaacs, & Muter, 1994). The influence of time since injury is attributed to the fact that, typically, most recovery occurs during the first 6 months after the injury, with recovery plateauing at 12 months post-injury (Fay et al., 2009). A longitudinal study of 79 children aged between 4 months and 7 years at time of injury who had sustained a mild-moderate (n = 35) or severe (n= 44) TBI produced results that confirmed this pattern of recovery (Ewing-Cobbs et al., 1997). Neuropsychological assessment occurred at baseline, 6 months, 12 months, and 24 months post-injury. Significant improvement from baseline to 6-month follow-up was evident on all assessment measures. There were no further changes in scores from 6 to 24 months post-injury.

Injury severity. Injury severity is a critical predictor of outcome and influences whether recovery after a TBI will follow a normal, routine path or a more prolonged one (Bennett & Raymond, 1997). Classification of brain injury occurs on a continuum ranging from mild to moderate to severe injuries. Severity of a brain injury is assessed on the basis of several indicators: (a) level of consciousness (as measured by the Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974), (b) length of loss of consciousness (LOC), (c) neurological status (for instance, midline shift, which indicates cerebral swelling), and (d) disorientation and loss of memory for events immediately preceding the accident (retrograde amnesia) or events following the event (posttraumatic amnesia) (Chapman & McKinnon, 2000; Bennett & Raymond, 1997; Satz, 2001).

Mild TBI. Mild injuries are classified as a GCS score of 13-15 (Nell, Yates, & Kruger, 2000). Children with TBI will generally experience a rapid, uncomplicated recovery with minimal persistent neuropsychological deficits (Catroppa & Anderson, 2003, 2005; Petersen, Scherwath, Fink, & Koch, 2008, Satz, 2001). This type of injury is typically followed by a short period of altered consciousness (less than 30 minutes) and, less likely, a period of post-traumatic amnesia marked by confusion and disorientation. Children with such injuries are rarely admitted to hospital; they are usually observed for a short period before being sent home (Bennett & Raymond, 1997; McAllister & Arciniegas, 2002; Ruff & Jurica, 1999; Satz, 2001; Satz et al., 1997). With regard to outcome in children who have experienced a mild TBI, studies present conflicting results: some report a good recovery, while others point to residual functional deficits (Hawley, 2003). Examples of both kinds of studies will be presented in turn.

Most studies suggest that mild TBI is associated with average cognitive performance with no evident persistent neuropsychological sequelae (Anderson et al., 2001; Carroll et al., 2004; Hessen, Netsvold, & Anderson, 2007). In a study involving 137 children with mild TBI and 132 controls, the former did not report more cognitive complaints (in the domains of attention, memory, and executive functioning) than did non-injured children (Asarnow et al., 1995). Similarly, McKinlay et al. (2002) found, in their prospective longitudinal study tracking a birth cohort of 1265 children aged 0 to 10 years, that children with mild TBI demonstrated no impairments in reading skills, language, mathematical abilities, and general academic achievement, regardless of the severity of the injury or age at injury. A review of studies published between 1970 and 1995 of mild TBI in children and adolescents also showed no evidence for long-term deficits (Satz, 2001). The methodologically stronger studies in this review reported null findings for academic and behavioural outcomes. In the cognitive domain, the majority of studies in the review revealed poor neuropsychological performance following mild TBI. However, methodologically stronger research showed these deficits to be transient, and to disappear, in most cases, after 6 to 12 months.

What is typically reported following a mild head injury is a constellation of short-term symptoms commonly known as post-concussive symptoms. These symptoms can be categorized into three groups: (i) neurocognitive difficulties (decreased memory, attention, and concentration), (ii) somatic complications (headache, fatigue, insomnia, dizziness, tinnitus, sensitivity to light or noise), and (iii) affective problems (anxiety, depression, irritability). However, these symptoms do not persist and usually resolve within months of the injury. Whether or not this group of symptoms constitutes a post-concussive "syndrome" as such is still being debated, with no real consensus on the issue (McAllister & Arciniegas, 2002; Petersen et al., 2008; Satz, 2001). There is consensus, however, that mild TBIs are associated with the appearance of post-concussive symptoms in the acute stages of trauma, but there is a debate around the persistence of deficits and whether they lead to the disabilities experienced by a some patients (Dikmen, Machamer, & Temkin, 2001; Hawley, 2003).

In one example of a study focused on post-concussive symptoms, Yeates et al. (1999) found that these symptoms were evident in 26 children (aged 8-15 years) with mild TBI. Of interest here was that the symptoms were exacerbated by premorbid neurological and psychosocial difficulties.

Numerous studies have provided evidence for long-term behavioural and academic problems rather than cognitive impairment following mild TBI (Borgaro, Prigatano, Kwasnica, & Rexer, 2003; McKinlay et al., 2002). A prospective study of 1 265 preschool children aged 0 to 5 years who had sustained a mild TBI, and a group of healthy controls, revealed that long-term behavioural impairments were reported more frequently by the mild TBI children (McKinlay et al., 2009). Mother/teacher behaviour ratings showed evidence for problems associated with attention-deficit/hyperactivity disorder, oppositional defiant disorder, and conduct disorder.

Researchers make the important distinction between 'complicated' and 'uncomplicated' mild TBI to explain the residual symptoms experienced by a small subset of this injury group. This percentage has been reported to be between 10 and 15% of all mild TBI cases (McKinlay et al., 2009). When mild TBI associated with a brief loss of consciousness presents with no evidence of a space-occupying lesion, it is classified as uncomplicated mild TBI. Children sustaining this type of injury typically make a very good recovery. Conversely, when a mild head injury is characterized by a brief loss of consciousness together with intracranial cerebral damage, it is classified as complicated mild TBI. Essentially, the characteristics of the TBI here 'complicate' the typical recovery from a mild TBI (Borgaro et al., 2003). A study comparing 130 children (6-15 years) with a mild TBI to 96 children with minor orthopedic injuries found that problems with headaches, dizziness, and fatigue resolved by 3 months post-injury for most mild TBI children. However, 17% of the patients in this group experienced persistent post-concussive symptoms and behavioural

problems. These residual deficits were associated with a premorbid history featuring TBI, learning difficulties, neurological or psychiatric problems, or family stressors (Ponsford et al., 1999).

Moderate and severe TBI. Moderate (GCS score = 9-12) and severe TBIs (GCS score < 9) are associated with a greater duration of loss of consciousness, larger size of lesion, and a longer length of post-traumatic amnesia. These injuries are associated with long-term, general cognitive dysfunction and typically follows a more protracted and multiphase recovery process, necessitating extended hospitalization and ongoing rehabilitation (Szekeres, Ylvisaker, & Holland, 1995). The *acute phase* of recovery focuses primarily on medical issues and ensuring survival. It is at this early stage that physical rehabilitation will begin. During the *early rehabilitation phase*, the identification of functional deficits and optimizing of recovery are prioritized. Finally, in the *chronic phase* acceptance and adaptation of the child and his/her family to impairments takes place, with lifelong medical and neuropsychological rehabilitation often following (Anderson et al., 2001; Bennett & Raymond, 1997; Nell et al., 2000).

TBI researchers have suggested there is a dose-response relationship between extent and severity of injury and outcome, with more severe TBI being associated with significantly worse outcome than mild TBI (Catroppa & Anderson, 2003; Ewing-Cobbs et al., 1998; Lord-Mayes & Obrzut, 1996; Willmott et al., 2000). Studies report moderate to severe TBI to be associated with long-term functional deficits (Anderson et al., 1997, 2004; Fay et al., 2009; Mangeot, Armstrong, Colvin, Yeates, & Taylor, 2002; Yeates et al., 2002).

To illustrate these principles, a prospective longitudinal study (Fay et al., 2009) investigated the relationship between injury severity, recovery, and outcome in 40 children with moderate TBI, 37 with severe TBI, and 44 with orthopedic injuries. All participants were between the ages of 6 and 12 years. Results suggested a strong link between injury severity and outcomes, with severe TBI predicting a stronger possibility of persistent deficits in neuropsychological performance (including in the domains of general intellectual functioning, language, visuo-motor abilities, and verbal learning), and in behavioural, adaptive, and academic functioning at 5 years post-injury.

Premorbid functioning. Indicators of trauma and age at injury alone cannot wholly account for the variability in neuropsychological and behavioural functional outcomes evident after childhood TBI (Anderson et al., 1997; Klonoff, Low, & Clark, 1997; Wassenberg, Max, Lindgren, & Schatz, 2004; Yeates et al., 2005). For instance, Anderson et al. (2006) compared children who had sustained a mild, moderate, or severe TBI, aged between 2.0 and 6.11 years at the time of injury, with healthy controls. Findings suggested that those children with poorer premorbid adaptive abilities (e.g., communication, daily living skills, and socialization) were at greater risk for developing long-term impairment in cognitive and behavioural functional outcomes.

Although pTBI researchers agree that accurate measurement of premorbid functioning is challenging, the fact remains that level of premorbid functioning is an important predictor of long-term outcome following TBI, and so it must be measured in one way or another. Some researchers interview the child's family as an attempt to determine premorbid levels of functioning (Anderson et al., 2001; Kersel, Marsh, Havill, & Sleigh, 2001; Levin, Song, Ewing-Cobbs, & Roberson, 2001; Yeates et al., 2002). For instance, parents might be asked about the child's medical and developmental history, parental level of education and occupation, and members composing the child's proximal family. However, reliance on this measure alone can be problematic due to parents, for instance, idealising the child or stated otherwise the parents do not acknowledge the child's impairments. The parents are, therefore, less likely to report any premorbid cognitive, scholastic, or behavioural problems, leading to a misrepresentation of the child's premorbid functional abilities and a less than accurate account of the changes since injury.

Psychosocial factors. As a predictor of behavioural and academic outcome, in particular, pre-injury levels of family function are important influencing factors (Anderson et al., 2001, 2006; Klonoff et al., 1977; Wassenberg et al., 2004; Yeates et al., 2002). Proximal family environments characterized by poor parental coping strategies and social stressors, as well as distal social environments typified by lower socio-economic status and fewer resources, are significant indicators of poor recovery profiles (Kinsella, Ong, Murtagh, Prior, & Sawyer, 1999; Max et al., 1998; Taylor et al., 1999, 2001; Yeates et al., 2004).

Numerous empirical studies have confirmed this relationship between psychosocial indicators and functional abilities. In a longitudinal study involving 53 children with severe TBI, 56 with moderate TBI, and 81 with orthopedic injuries (all aged between 6 and 12 years), results showed that poorer behavioural outcomes were predicted by adverse social and family environments (Taylor et al., 2002). Low socio-economic status, low annual family income, and fewer years of maternal education were indicators of adverse social environments. Adverse family environments were indicated by the presence of family social stressors and poor resources. Yeates et al. (1997), in their investigation of 53 children with severe TBI, 56 with moderate TBI, and 80 with orthopedic injuries (aged between 6 and 12 years) found similar results. Specifically, premorbid family environment was predictive of functional outcome, with impact of the injury being aggravated in low-functioning families and diminished in high-functioning families.

With regard to mechanisms explaining the results presented in the studies reviewed immediately above, one suggestion is that the effect of family factors on behaviour and scholastic performance can be explained by the benefits associated with living in an advantaged environment. In such circumstances, children receive more stimulation and support from family and other important role players (Taylor et al., 2002). Furthermore, in addition to the difficulties related to the

actual injury, parents from a more disadvantaged background may not be able to afford adequate rehabilitative assistance, and may have even more financial pressure heaped on them by their child's injury (Yeates et al., 2002). This additional financial burden comes in the form of payment for hospital stay, loss of income, and prolonged medical care. The major concern becomes not the child's injury, but rather the need to exist financially.

Following the evidence that functional deficits can persist months or even years following a childhood injury, the discussion that follows will center on the nature of specific neuropsychological impairments associated with TBI.

Neuropsychological sequelae of TBI. With specific regard to neuropsychological outcome following TBI, the domains of attention and concentration, memory and learning, and executive functioning have recently received considerable attention. The reason for this focus that these domains have been reported to be the most commonly affected following a childhood TBI (Mateer, Kerns, & Eso, 1996), and because these domains are especially vulnerability to interference by acquired and developmental disorders (Ewing-Cobbs et al., 1998). In a study typical of those in this area, Yeates and colleagues (2002) reported that children aged between 6 and 12 years at the time of injury and who had sustained a moderate to severe TBI, consistently showed poorer neuropsychological performance than controls. Deficits were demonstrated across the following domains: general intellectual functioning, language, memory, visuo-perceptual abilities, and attention and executive functions.

General intellectual functioning. Children with mild injuries TBI tend to score in the average range on IQ tests (Catroppa & Anderson, 2003; Muscara et al., 2008; Ponsford et al., 1999). For instance, a study with of TBI children between the ages of 2 and 6 years showed that mild and moderate TBI participants performed within the average range for PIQ, with scores not significantly different from age-matched controls. In contrast, severe TBI participants performed significantly more poorly, with their mean score falling well below the average range (Anderson et al., 2004). A second study of 79 college students with a history of mild TBI, 75 with a history of general anesthesia, and 93 with no history of mild TBI or general anesthesia found no IQ deficits in those students with a history of mild TBI in childhood or adolescence (Marschark, Richtsmeier, Richardson, Crovitz, & Henry, 2000). Anderson and colleagues (2001) assessed 17 children with mild TBI and 35 non-injured children aged 3 to 7 years at baseline, 6 months, and 30 months post-injury. Results revealed FSIQ to be within the normal range for children with mild injuries.

Impaired performance on tests of general intellectual functioning emphasise the generalized nature of cognitive deficits in moderate to severe TBI, where intellectual abilities are often globally depressed with decline in both Verbal IQ (VIQ) and Performance IQ (PIQ) scores (Anderson et al., 2000, 2004, 2006; Catroppa & Anderson, 2005; Ewing-Cobbs et al., 1997; Fay et al., 2009;

Robertson et al., 1996). Specifically, PIQ is more impaired in pediatric TBI than is VIQ. For instance, by 1 year post-injury, children with severe TBI continue to exhibit PIQ deficits while VIQ returns to normal (Catroppa & Anderson, 2003). VIQ has been reported to be relatively spared even in the acute phase, suggesting that "crystallized" knowledge such as that based on fund of semantic information and word knowledge is relatively unaffected. The vulnerability of PIQ ("fluid" abilities) on the other hand is indicative of impairment in skills such as reasoning, problem solving, speed of response, and psychomotor coordination (Anderson et al., 2001). Anderson and colleagues (1998) found contradictory results when they compared 18 children with moderate-severe TBI to 18 controls. Participants were aged 8 to 14 years and were at least 2 years post-injury. VIQ scores were significantly lower for TBI children compared to controls. PIQ scores showed poorer results for the head injured children, but differences were not statistically significant.

Similar trends to the results found by Catroppa and Anderson (2003) were found in a South African study of TBI children between the ages of 6 and 14 (Hemp, 1989). That is, participants in a group defined as "very severe" TBI showed significantly lower PIQ scores than did age-matched controls or participants in other TBI groups. Furthermore, participants in a combined moderate-severe TBI group scored significantly lower on the PIQ measure than did controls.

An important factor to consider here is the fact that the IQ measures used in the studies described above were developed and normed in the First World nations that typically do not include divergent cultures. Nell (2000, 2007) argues that normative data for IQ measures is surrounded by controversy when these measures are used by neuropsychologists in South America, Africa, and Asia. The same is true for measures of attention, memory, and executive functions. As was previously discussed, the cross-cultural appropriateness of internationally developed norms is a situation that needs serious consideration.

Attention. Attention is a multi-component system: Different kinds of attention rely on different brain systems (Fenwick & Anderson, 1999; Gitelman, 2003; Manly, Robertson, Anderson, & Nimmo-Smith, 1999). *Sustained attention* is the ability to maintain attention over a long period of time; it is marked by vigilant behaviour. *Selective attention* (sometimes called *focused attention*) is the ability to discriminate important stimuli from irrelevant information, or the ability to focus on a single stimulus while ignoring distractors. *Divided attention* is the ability to attend to two competing stimuli at the same time. *Shifting attention* is the ability to flexibly switch attention from one dimension or rule to another within a single task (Catroppa & Anderson, 2003; Willmott et al., 2000). The child with attentional dysfunction is unable to attend properly to environmental cues and will therefore experience difficulty learning new knowledge and skills, with detrimental effects on his/her academic performance.

Mild TBI is conventionally associated with average performance on measures of attention (Carroll et al., 2004; Hawley, 2003; Ponsford et al., 1999). However, some evidence does exist that even children with mild TBI may still experience some residual attentional impairment. For example, in a study of 15 children with mild TBI and 15 controls (all aged 6 to 12 years), those in the patient group demonstrated some difficulty on tasks of selective attention (Catale, Marique, Closset, & Meulemans, 2009). Furthermore, a case study of a mild TBI child, aged 7 at the time of injury also presented evidence of persistent attentional difficulty at 4 years post-injury (Roberts, Manshadi, Bushnell, & Hines, 1995).

Children who have sustained moderate to severe TBI experience deficits in all four of the attentional systems described above (Anderson et al., 2001; Fenwick & Anderson, 1999; Lowther & Mayfield, 2004; Yeates et al., 2002). Again, a dose-response relationship is demonstrated here, with more severe injuries being associated with more severe attentional impairment (Catroppa & Anderson, 2005; Ewing-Cobbs et al., 1998; Kersel et al., 2001; Wassenberg et al., 2004; Willmott et al., 2000; Yeates et al., 2002, 2005). For instance, in a study of children aged between 4 months and 15 years who were at least 5 to 8 years post-injury, severe TBI participants performed more poorly on tests of shifting attention than did participants with less severe head injuries (Ewing-Cobbs et al., 1998). Similarly, Catroppa and Anderson (2003) investigated the impact of injury severity on sustained attentional abilities. They found that participants with severe TBI performed significantly worse than those with mild TBI on more complex tasks requiring speed, accuracy, and decision-making skills. Finally, Anderson and colleagues (1998) investigated attentional skills in 15 children with moderate-to-severe TBI and 18 controls. All participants were between the ages of 8 and 14 years of age. Results indicated that those with moderate-to-severe TBI demonstrated profound deficits in sustained and divided attention and response inhibition, whereas focused attention was relatively spared.

There have been no published research studies of attentional functioning in South African TBI populations.

Memory. Everyday tasks of childhood involve learning and acquiring new knowledge. The effects of memory impairment following TBI can therefore be quite substantial, with major implications for the child's psychosocial development and functioning (Anderson et al., 2001). Particularly within the school environment, the child is required to learn new information about rules of conduct, as well as information relevant to the development of his/her scholastic abilities. Further, the child must be able to retrieve this information as the situation requires.

Like attention, memory is a multi-faceted system, with processes ranging from registering information, encoding and storing that information, and then later retrieving it. Otherwise stated,

memory is an active process that directs attention, implements encoding strategies (e.g., rehearsal), and controls retrieval (Catroppa & Anderson, 2002).

With regard to the taxonomy of memory systems, memory function can also be understood in terms of declarative versus procedural or explicit versus implicit memory (Schacter, 2007; Squire, 2007; Yeates & Enrile, 2005). Declarative or explicit memory is representational and is associated with conscious recollection. Declarative memory is characterized as episodic and semantic memory which is acquired through our conscious memories by means of personal experiences. Episodic memory involves knowledge of specific, everyday events or episodes which are encoded as they occur. Semantic memory involves factual knowledge of the world. Procedural or implicit memory, on the other hand, describes memory for a skilled, habitual activity, like riding a bicycle, for which there is no conscious recall or awareness that memory is being used. Procedural memory represents the ways in which we have learned to interact with the world and provides a way to model the external environment (Eichenbaum, 2002; Squire, 2007. Regardless of which memory system one discusses, intact function is of critical importance for scholastic achievement (Ewing-Cobbs et al., 1995).

Children with TBI show a consistent trend of generalized deficits in encoding, storage, and retrieval processes (Anderson et al., 2001). For instance, Lowther and Mayfield (2004) showed that children with TBI were impaired on tasks of immediate recall and 30-minute delayed recall for both verbal and visual material. A more fine-grained study focusing on children between the ages of 6 and 12 years who had sustained a moderate to severe TBI showed similar trends (Yeats et al., 2002). That study's findings indicated that participants in the severe TBI group performed more poorly than did controls on tests of verbal learning and recall; those in the moderate TBI group showed less pronounced impairments while still differing from the control group on several outcome measures. A case study of a child aged 7 years at the time of injury also illustrated persistent memory gaps for personal experiences at 4 years post-injury (Roberts et al., 1995).

With regard to trajectory of recovery of memory function, children who have sustained mild or moderate TBI typically show such recovery within 12 months post-injury. Those with severe TBI, in contrast, demonstrate slower and less complete recovery of memory function (Anderson et al., 2000; Catroppa & Anderson, 2003, 2005). A longitudinal study with 76 children who sustained a mild, moderate, or severe TBI investigated recovery patterns in immediate and short-term memory, and multi-trial learning skills. All the participants were between the ages of 8 and 12 years. Compared to the mild and moderate TBI groups, children with severe TBI demonstrated more pronounced memory deficits at the acute, 6-, and 12-months post-injury testing stages.

Similar trends as those described above emerged in the South African study conducted by Hemp (1989). That is, participants in the 'very severe' TBI group scored lowest on all memory

measures, but even moderate and severe TBI participants scored significantly more poorly than did control participants at 1 year post-injury.

Executive functioning. Executive functioning can be defined as the superordinate management capacity that directs and regulates modular abilities including language, memory, attention, motor skills, and managing and attaining goals (Elliott, 2003; Levin & Hanten, 2005). More specifically, these superordinate capacities include maintaining a problem-solving repertoire for future goals, planning (or the organization of behaviour), ensuring flexibility in problem-solving, self-monitoring and self-regulation (inhibiting inappropriate behavioural responses), conforming to the rules of social behaviour, using strategies in a skillful manner, monitoring, processing, and maintaining relevant information to guide behaviour and cognition (working memory). The large umbrella of executive function also includes abilities involving self-appraisal and self-management (metacognition), attentional control, and the use of reward and punishment to facilitate learning (Anderson, 2002; Gioia, Isquith, Kenworthy, & Barton, 2002; Levin & Hanten, 2005; Mandalis et al., 2007).

Clearly, executive skills impact upon all aspects of behaviour. Executive impairment may be demonstrated by poor planning and organization, difficulty generating and implementing problem-solving strategies, cognitive inflexibility, an inability to self-correct, impaired reasoning, poor social judgment, and perseveration (Elliott, 2003; Gioia et al., 2002; Stuss & Benson, 1984). The behavioural dimensions of executive dysfunction typically include poor self-control, poor inhibitory control, behavioural apathy, poor initiation, and inflexibility (Busch, McBride, Curtiss, & Vanderploeg, 2005).

The development of executive skills throughout childhood corresponds to growth spurts (or developmental stages) in the prefrontal cortex. These cerebral regions are dependent upon the integrity of other cerebral areas and, as a consequence, the development of executive functions is associated with the emergence of other cognitive abilities, such as language and memory. Therefore, the normal development of executive skills relies on the integrity and uninterrupted maturation of numerous associated brain regions (Anderson et al., 2004; Mandalis et al., 2007; Sohlberg & Mateer, 2001; Tranel & Eslinger, 2000; Willmot et al., 20007). The development of socially appropriate and acceptable behaviour is thus dependent upon the integrity of these brain regions (Anderson, 2002).

With regard to studies of executive functioning in children with mild TBI, results are inconsistent. For example, Maillard-Wermelinger and colleagues (2009) compared 186 children with mild TBI to 99 children with mild orthopedic injuries. All participants were aged 8 to 15 years. Findings revealed little evidence for cognitive or behavioural executive dysfunction, and, in fact, mild TBI children surprisingly demonstrated better performance on measures of working memory

than controls. Conversely, in a study of 15 children with mild TBI and 15 healthy controls, the former demonstrated poorer performance than the latter on tasks assessing executive skills, specifically the ability to update tasks (Catale et al., 2009).

Moderate to severe TBI is associated with numerous executive function deficits: poor planning and problem solving, slowed speed of response, impaired working memory, depressed metacognitive processing, and a reduced capacity for abstract thinking (Ewing-Cobbs, Prasad, Landry, Kramer, & DeLeon, 2004; Hanten, Bartha, & Levin, 2000; Hanten et al., 2008; Hanten, Zhang, & Levin, 2002; Levin, Song, Ewing-Cobbs, Chapman, & Mendelsohn, 2001; Mandalis et al., 2007; Muscara et al., 2008; Nadebaum, Anderson, & Catroppa, 2007; Roncandin, Guger, Archibald, Barnes, & Dennis, 2004; Wozniak et al., 2007). For instance, Mongeot and colleagues (2002) showed that, in children who had sustained moderate to severe TBI and who were between the ages of 10 and 19 years and at least 5 years post-injury, executive functions, particularly metacognition, working memory, and behavioural control, were significantly impaired. Levin and colleagues (2004) showed working memory to be impaired in a sample of 144 children (aged 8-13 years) with a mild, moderate, or severe TBI. Severe TBI children performed significantly more poorly on working memory tasks than did those with mild and moderate injuries.

Further, more impaired performance on executive functioning tasks is associated with a younger age at injury (Ewing-Cobbs et al., 2004; Levin & Hanten, 2005; Nadebaum et al., 2007; Ward et al., 2007; Warschausky, Argenta, Hurvitz, & Berg, 2003). A study with 68 children aged 7 to 15 years who had sustained a moderate to severe TBI investigated the relationship between age at injury and executive functioning (Slomine et al., 2002). The participants were at least 12 months post-injury and were tested on their problem-solving ability, their ability to use flexible cognitive processes, novel lexical search abilities, and word generation skills. Younger age at injury was associated with deficits in problem-solving and word generation abilities. Finally, impaired problem-solving and word generation skills were found to be characterized by preservation errors.

There have been no published research studies of executive functioning in South African pTBI populations.

A Gap in the South African Literature on TBI

There is a considerable lack of recently published research on neuropsychological sequelae of TBI in South African pediatric populations; most recent studies of TBI in this country address epidemiological issues. Indeed, with the exception of the unpublished doctoral thesis by Hemp (1989), all of the South African studies that could be found investigated incidence rates, mechanisms of injury, and age and gender distributions in pTBI (e.g., De Villiers et al., 1984; Lalloo & van As, 2004). Further, the only South African study reviewed that considered outcomes

was that by Semple and colleagues (1998). However, their investigation involved an assessment of *neurological* outcomes following pTBI. Good outcome was defined as normal neurological state or persistent neurological deficits while poor outcome was defined as death or a persistent vegetative state.

The Role of Neuropsychological Assessment in pTBI

The child with TBI, particularly of the mild type, does not generally exhibit any noticeable physical deficits and is often assumed to have made a 'complete recovery' from his or her head injury. As such, after the acute phase of recovery, the brain injury often becomes "invisible" to family and to friends, as well as to educators and other professionals (Koskinen & Alaranta, 2007, p. 205; Laatch et al., 2007). This situation results in the child's need for intervention being missed, so that he/she is returned to the home and school environment without a framework of cognitive strengths and weaknesses within which the child, parents, and teachers can operate (Brenner et al., 2007).

Neuropsychological assessment post-TBI plays a crucial role in ensuring that compromises in brain functioning do not remain invisible to the child, parents, teachers, and other relevant parties. Stated otherwise, it directs knowledge to essential role players in the child's life and enables optimal functioning following trauma. The primary goal of this assessment, then, is to measure current functioning and use that measurement to predict long-term functional outcome of the child in his/her environment; all of this is accomplished by identifying manifest disabilities and the relationship between these disabilities and a set of basic skills (Ewing-Cobbs & Fletcher, 1987; Ewing-Cobbs et al., 1995; Sherer et al., 2002).

More specifically, the neuropsychological assessment post-TBI can be broken down into several steps, each, perhaps, serving a slightly different purpose. Firstly, assessment during the subacute period of recovery provides a baseline description of cognitive functioning that allows for the monitoring of recovery or deterioration over time. Secondly, assessment at any time post-TBI, but particularly during subacute period of recovery, allows for the formulation of a prognosis. Thirdly, assessment informs the formulation of a comprehensive treatment plan. Finally, repeated neuropsychological assessment enables the identification of changing patterns of strengths and weaknesses which, in turn, aid in evaluating the efficacy of a treatment plan (Baxter et al., 1995; Ewing-Cobbs & Fletcher, 1987).

Within both clinical and research settings, quantitative, standardized psychometric and neuropsychological measures provide objective norms against which the child's cognitive functioning can be compared to that of his/her peers. Qualitative, clinical judgment also forms an integral part of the assessment process, particularly in facilitating the clinician's ability to obtain

valuable insight into the nature of cognitive deficits. However, these latter approaches are unable to provide objective information with regards to the child's developmental level, and possible deviations from age-appropriate norms. Therefore, in order for neuropsychological assessment to be clinically relevant, it must consider *both* quantitative and qualitative information (Anderson, et al., 2001).

The therapeutic role of neuropsychological assessment becomes evident when standardized testing together with medical history, behavioural assessment, parents' observations, and teachers' reports, provides a comprehensive and careful analysis of test performance. An integrated approach such as this generates a comprehensive and accurate picture of the child's abilities and deficits. This information, when communicated to the child, family, and teachers, as well as to other professionals involved in the recovery process, can facilitate support and allow for the management of the resultant functional deficits within the home and in the wider social environment (Ewing-Cobbs & Fletcher, 1987).

A Culturally-Sensitive Battery Approach

Most assessment tools used by South African neuropsychologists were developed and normed in First World countries (Cohen & Malcolm, 2005). These countries all feature quite different socio-economic and cultural contexts from those found in developing-world nations such as South Africa, which are relatively resource poor and much more culturally heterogeneous. Clearly, then, there is a need within South African clinical and research neuropsychology not only for locally appropriate normative data that can be applied to instruments developed overseas, but also for culturally appropriate assessment instruments. As noted earlier, the current study forms part of a research program that aims to establish a reliable and valid standardised battery of culturally relevant neuropsychological assessment tools that is sensitive to TBI within the South African pediatric population.

Establishing a neuropsychology battery specific to pediatric TBI in South Africa. The generation of a core test battery will benefit the practitioner and the researcher in that norms will be available for comparison of a child's neuropsychological test performance against 'normal' scores (Carroll & Horn, 1981; Green, 1981). In addition, there is the added advantage of having at their disposal a battery that can be tailored to each patient's individual needs (Brooks, 1995; Nell, 2000). Haney (1981) states that the success of psychometric testing as a reliable measurement tool has already been established. Many studies around the world have attempted to develop standardized and normed batteries targeted at various populations. For instance, Woods and colleagues (2006) undertook the task of establishing standardized norms for a battery of commonly used neuropsychological testing devices, with the aim of using that battery in the assessment of HIV-

positive individuals. The study demonstrated the functionality of this battery in detecting changes in neuropsychological performance of 29 adults with HIV-1 infection. Changes in cognitive functioning were measured by examining the specificity of an adapted Reliable Change Index (RCI) methodology when applied across a battery of frequently used neuropsychological tests. The Reliable Change Index plus practice effects (RCI + P) model is a statistical measurement in the assessment of cognitive change. Measurement of cognitive change is achieved through the prediction of follow-up test scores by adding individual baseline test scores to the mean practice effect of the reference group. Fifty seven healthy controls with a mean age of 24.9 (11.3) and average years if education 13.1 (2.3) were assessed twice with the time points separated by a 12 month interval. Test-retest reliability coefficients and standard RCI confidence intervals for each measure were equivalent to previous normative research. The RCI normative data proved to be adequately specific when the battery was administered to the 29 adults with HIV-1 infection who were categorized as medically and neurologically stable. The findings from this study provided standardised norms for detecting cognitive changes across a battery of commonly used neuropsychological measures.

The study described above serves as a guide to what the current study ultimately hoped to accomplish in terms of generating South African normative standards for neuropsychological tests commonly used in the assessment of pediatric TBI.

***The need for statistical objectivity*.** The importance of a battery with standardized norms is especially evident when considering clinicians involved in medico-legal cases where they have to testify as expert witnesses. Over the last one hundred years, both international and local courts have increasingly come to rely on psychologists as expert witnesses (Allan, 2005; Cohen & Malcolm, 2005; Elwork, 1984; Gudjonsson, 1995). As a result, psychological testing is the one activity most examined and scrutinized by the legal profession. Though clinical judgment is an invaluable component of conclusions drawn from neuropsychological assessment, in a court of law objective, quantifiable psychometric measures are less vulnerable to criticism than testimony based on subjective, clinical judgment (Ogloff, 2002). By its very nature, clinical opinion is inherently biased, a bias that can lead to the reporting of misleading evidence. Standardized neuropsychological measures can serve as a buffer against the unreliability of prejudiced testimony (Bersoff, 1981; Frazier & Borgido, 1992; Glaser & Bond, 1981; Martell, 1992; Marlowe, 1995; Mauer, 2000; Schuller & Vidmar, 1992; Schwartz & Goodman, 1992).

When instruments have internal validity, have endured numerous past evidentiary enquiries, and/or when they are in use by a large number of members of a recognized profession, courts recognize such measures as reliable (Allan, 2005). The four main criteria that need to be met in South African courts (as well as internationally) are content validity, construct validity, reliability,

standardization, and accompaniment by a manual. The test manual should explain item and norm development and summarise internal and external validity and reliability data, procedures for administration, scoring and interpretation. In addition, assessment devices must be relevant to the specific legal or psychological issue under question. Preferably, published, empirical research must provide collaborative evidence for the relevance of a test. However, Allan (2005) stresses the importance of using internationally normed measures prudently in the South African legal context.

The move of the South African judicial system towards quantifiable evidence is illustrated in various civil and criminal proceedings. For example, in compensation for brain injury litigation, the psychologist, as an expert witness, is required to employ a standardized battery for a comprehensive assessment of neuropsychological functioning. He/she must report objective scores that are clinically interpreted in terms of the patient's injury and pre- and post-morbid functioning (Brooks, 1995). According to Nell (2000), when dealing with brain injury compensation cases, the absence of norms leads to questionable forensic validity of neuropsychological measures. This situation results in courts having to revert to medical evidence to ascertain whether a brain injury has been sustained or not.

With regards to employment litigation, legal standards have increased the role of psychometric analyses to either prove or disprove inequality in hiring and promotional standards (Schwartz & Goodman, 1992). In South Africa, the Parliamentary Portfolio Committee on Labour has formulated legislation in the form of the Employment Equity Act (number 55 of 1998) that requires utilization of scientific psychometric devices that fulfill internationally recognized standards of assessment practice (Mauer, 2000; van de Vijver & Rothmann, 2004). The Employment Equity Act (EEA) states that:

> Psychometric testing and other similar assessments of an employee are prohibited unless the tests or assessments being used –
>
> (a) has been scientifically shown to be valid and reliable;
>
> (b) can be applied fairly to all employees; and
>
> (c) is not biased against an employee or group
>
> (Chapter 2, Section 8).

The following examples are further illustrations of the legal system's endorsement of standardised psychometric measures as a means of providing reliable evidence. In the United States of America, the Supreme Court expressed reservations around clinical opinion as testimony in rape criminal cases (Frazier & Borgido, 1992). Questions were raised about the applicability of expert testimony based on rape trauma syndrome (RTS). RTS testimony is controversial as it is based on a description of the common effects after the rape has occurred and the expert's opinion that a particular complainant's behaviour is indicative of having been raped. Though not specifically

related to expert testimony, the South African case cited in the following example also demonstrates the courts' approval of employing psychometric tools in the gathering of evidence. The Magistrate's Courts have referred a number of rape survivors believed to be mentally disabled for assessment of cognitive functioning using standardised psychometric tools (Pillay & Sargent, 2000). This was done to ensure that survivors were cognitively capable of giving consistent evidence.

Developing cross-culturally appropriate instruments. The inescapable truth remains that despite their widespread use, most neuropsychological instruments are developed using normative samples that are White, middle-class, English-speaking, and well-educated (Allan, 2005). This poses an enormous barrier for clinicians and researchers who have to assess individuals from culturally and linguistically diverse populations (Foxcroft, Paterson, le Roux, & Herbst, 2004; Manly, 2008; Mindt et al., 2008; Pedraza & Mungas, 2008). To ensure cross-cultural diagnostic validity, neuropsychological measures must consider the cultural factors underlying disparities in cognitive test performance (Ardila, 2007; Ardila & Keating, 2007; Ardila & Roselli, 2007; Dotson, Kitner-Iriolo, Evans, & Zonderman, 2009; Glymour & Manly, 2008; Glymour, Weuve, & Chen, 2008; Sticks, Pittman, Jacobs, Sano, & Stern, 1998). Pedraza and Mungas (2008) suggest that cross-cultural assessment essentially means that the same or similar cognitive functions are being assessed across divergent cultural groups. Furthermore, cross-cultural methods must define and acknowledge diversity and similarity between two or more different cultural groups.

When neuropsychological test instruments measure cognitive abilities, they are in effect measuring culturally learned abilities (Uzzell, 2007). A problem here is that what is deemed relevant and worthy of learning for a South African child is not necessarily the same for a child from England. Although some universals exist among cognitive abilities, there are cultural differences in the patterns of skills. For example, cultural norms often prescribe which genders will learn which abilities and by what age, leading to sex-based discrepancies in the trajectory of patterns of cognitive functioning. Furthermore, with regards to non-verbal abilities like copying figures, listening to tones, and drawing maps, the influence of culture is also unmistakable. Copying a "nonsense figure" like the Rey-Osterrieth Complex Figure (ROCF; Osterrieth, 1944), for example, might seem strange for a non-psychometrically oriented child from a non-Western culture, but would be completely acceptable for an American school child (Ardila, 2007, p. 26). Cultural influences are also evident in verbal abilities where, for example, certain question formats in exams can be difficult to comprehend for certain individuals, leading to poor test performance by those individuals.

It is not difficult to predict, then, that the best test performances are typically found in those test-takers from the same culture as that where the measures were normed. The impact of culture on neuropsychological test performance was found in language and speed of processing abilities

among 11 African-American and 11 European-American HIV-1 positive children (Llorente, Turcich, & Lawrence, 2004). Participants were all aged between 5 and 7 years; the groups did not differ with regards to age, immunologic clinical category, overall intellectual ability, level of maternal education, and CD4+ percentage. The African-American children scored lower than their European-American counterparts on both the Expressive One-Word Picture Vocabulary Test-Revised (EOWPVT-R; Gardner, 1990) and the Rapid Color Naming test (CTOPP; Wagner, Torgesen, & Rashotte, 1999), however. Similarly, a study comparing 42 healthy Russian and 42 healthy American participants (all aged between 18 and 44 years) on a battery of neuropsychological tests found cross-cultural differences in measures of attention and concentration, non-verbal fluency, divergent thinking, ability to shift cognitive set, and planning. The American participants demonstrated a better performance than their Russian counterparts on the Ruff Figural Fluency Test (RFFT; Ruff, 1996) and the Color Trails Test(CTT; D'Elia, Satz, Uchiyama, & White, 1994), with their superior performance attributed to greater cultural familiarity with timed tests (Agranovich & Puente, 2007).

A study by Hudson (1960) is illustrative of cross-cultural differences in cognitive abilities. Depth perception was assessed in 6 school-going samples (3 White and 3 Black) and 5 non-school-going samples (1 White and 1 Black) from Europe and Africa. The task involved pictures of figures of an elephant, an antelope, and a man with a spear. The participants had to explain what the man was doing with the spear. Four pictures with different cues for interpretation of the pictures were available. European children aged 7-8 years experienced difficulty perceiving the picture as three-dimensional. By age 12, however, all children in this group perceived the picture as three-dimensional. The same pattern of data was not evident for African children, with high school pupils and graduates performing no better than European Standard 6 (Grade 8) pupils.

Roselli, Ardila, Bateman, and Guzmán (2001) also demonstrated cultural differences in abilities when they compared 290 Colombian children between the ages of 6 and 11 years to American norms. The children were assessed on measures of verbal memory, nonverbal memory, constructional abilities, motor skills, executive functions, and nonverbal auditory discrimination. Test scores of the Colombian children were similar to the norms. However, on the task for nonverbal auditory discrimination, the Colombian children outperformed the American group. The inference was drawn that musical learning has significant cultural value to Colombian children which explains why nonverbal abilities were better developed in Colombian children.

In addition to considering cultural differences in cognitive abilities, it is also important to take into account the influence of cultural constructs on neuropsychological test performance. The concepts subsumed under the term culture include language, quality and level of education, and socioeconomic status (SES); all of these have to be considered when administering

neuropsychological measures to different cultures and attempting to compare results across cultures (Ardila & Roselli, 2007; Nell, 2000). Research findings suggest that these factors strongly influence neuropsychological test performance (Bender et al., 2009; Dotson et al., 2009; Glymour & Manly, 2008; Sticks et al., 1998). One typical study in this field of research featured the administration of a brief neuropsychological test battery to 20 Aruaco Indians (12 males and 8 females, aged 8 to 30 years; Ardila & Moreno, 2001). On some tests (those that featured stimuli that were meaningful and significant to them), the participants performed almost perfectly when compared to established norms. In contrast, on those tests that featured stimuli that were meaningless to them and difficult for them to interpret, the participants performed exceptionally poorly when compared to established norms. The researchers established that both cultural relevance of test stimuli and educational level of the participants significantly influence performance on the battery. Specifically, low educational levels and measures that were not culturally relevant were associated with poor performance.

With regard to the effects of SES on neuropsychological test performance, research conducted in Australia has demonstrated that children from a lower SES are at greater risk of long-term neuropsychological deficits following brain injury (Anderson et al., 2004). Similar effects have been demonstrated in non-clinical populations. Dotson and colleagues (2009) demonstrated that both racial minority status and low SES negatively affect test performance in US samples. In their study, they compared low and high SES African-Americans and Whites. Results showed that low literacy levels were associated with poor cognitive performance in both low- and higher SES African Americans and low SES Whites. In higher SES Whites high education levels and reading scores predicted better cognitive performance.

The influence of literacy and educational levels on cognition is, in turn, affected by the disadvantages related to racial minority status and low SES. Low education levels and poor educational systems are linked to low SES where the schools are poorly resourced and exposure to books in the home is not adequate. People with a low SES background may experience less stimulation at home resulting in low SES being associated with poorer cognitive abilities (Ardila & Roselli, 2007).

The studies reviewed above clearly indicate the importance of considering the relevance of instruments developed and normed in First World countries when testing in culturally divergent populations. A test must be meaningful in terms of language and cultural appropriateness of test items. Furthermore, SES and quality and level of education are important factors to consider when interpreting neuropsychological test performance.

Attempts at Developing Cross-Cultural Neuropsychological Instruments

To ensure that cross-cultural neuropsychological examination is possible, items have been translated from instruments developed in one cultural setting to that of another language and culture (see, e.g., Pedraza & Mungas, 2008). However, this strategy presents some measure of difficulty due to the lack of normative data for the second language and culture. By simply translating standardized tests in the absence of appropriate norms, the assumptions on which the tests were originally normed are being violated, compounding the potential for cross-cultural variability in performance (Uzell, 2007). Olmedo (1981) points out that when measures are translated into other languages, the domains assessed by the different language versions may have few similarities, and the psychometric properties underlying test items might be very different from the original items. Consequently, results that are technically dissimilar to the original form of the assessment tool are generated. Therefore, when using standardised tests that have been normed in a different culture from the population being tested, inferences and conclusions drawn from test results may be invalid.

As an illustration of this point, performance on the Spanish version of the Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtiss, 1993) was investigated in 52 Mexican-American adults (Coffey, Marmol, Schock, & Adams, 2005). Performance was within the average range when compared to Spanish normative data. However, the Mexican-American group demonstrated significantly poor performance when compared to normative data derived from an English-speaking North American population.

Despite these issues, some researchers have made attempts to demonstrate that tests developed in First World countries are applicable for use in resource-poor, developing-world countries (Ardila & Moreno, 2001; Bender et al., 2009). For instance, Shuttleworth-Edwards, Donnelly, Reid, and Radloff (2004) showed, in a South African study involving 68 participants between the ages of 19 and 30 years, that the WAIS-III Digit Symbol-Incidental Learning subtest was a relatively culturally unbiased task with valid efficacy as a neuropsychological screening tool.

Other researchers have adopted the approach of collecting locally-appropriate normative data for foreign-developed instruments to ensure that cross-cultural examination is made possible. For instance, Kosmidis, Vlahou, Panagiotaki, and Kiosseoglou (2004) used a sample of 300 healthy adults to generate normative data for the Greek population, stratified by age and level of education, for measures of semantic and phonemic fluency. Similarly, Sticks and colleagues (1998) administered a brief neuropsychological battery to 995 normal elderly participants (English- and Spanish-speaking, stratified by age and education level) in an attempt to develop norms for a non-English-speaking population with low levels of education.

It is important to note that none of the studies reviewed above, except for Ardila and Moreno (2001), included children in their sample. This is no coincidence; there are few cross-cultural neuropsychological studies that focus on pediatric populations.

A Need for Pediatric Cross-Cultural Neuropsychology

Information on the presence, magnitude, etiology, and implications of culture-bound disparities in cognitive functioning among children is very limited. The growing body of evidence supporting cross-cultural assessment has primarily relied on adult and elderly Caucasian, African-American, and Hispanic populations. Byrd Arentoft, Scheiner, Westerveld, and Baron (2008) identify six areas in need of scientific research in both normally developing and neurologically challenged children: (i) the establishment of equivalent forms of neuropsychological tests across different cultures, (ii) the presence of degree and domain specificity of disparities in cognitive abilities due to ethnicity, (iii) etiology of observed disparities, (iv) the emergence and developmental pattern of disparities, (v) the relationship between TBI and cultural performance trajectories, and (vi) the clinical management of culture bound differences in functioning and implications for recovery and intervention. Ultimately, methodologically strong research on the issues raised above will facilitate progress in the field of child neuropsychology.

Vigorous research similar to that conducted by Mulenga, Ahonen, and Aro (2001) is needed to augment what literature there is to be found for pediatric samples. Mulenga and colleagues conducted their investigation on 45 Zambian school children between the ages of 9 and 11 years in an attempt to produce preliminary findings as to the clinical usefulness of the NEPSY, a comprehensive battery that tests cognitive abilities in key neuropsychological domains, in a non-Western cultural context. The children demonstrated poorer performance in the domains of language, attention, and executive functioning when compared to US normative standards. Due to the small sample size, the researchers could only tentatively suggest that the NEPSY might be a useful cross-cultural neuropsychological tool and that factors such as culture, language, and personal demographic information (level and quality of education, SES) be taken into account.

Specific Aims and Hypotheses

Due to the generalized profile of cognitive dysfunction associated with a closed head injury, this injury classification was the focus of the present research. Following the mechanism associated with early vulnerability, the current study operates on the premise that neuropsychological sequelae will persist for months, and even years, after the injury has occurred. This research therefore attempted to provide an updated profile of cognitive functioning following TBI in South African children. The present study is thus in many ways a follow-up to the doctoral thesis presented by Hemp (1989). Furthermore, this study will lay the framework for developing a battery of neuropsychological measures and providing guidelines for culturally relevant norms that will be useful in both clinical and research practice in South Africa.

Although the study is not of an experimental (or even quasi-experimental) design, the general hypotheses might be stated as follows:

(i) children with TBI will perform significantly more poorly on the measures of cognitive functioning than age-, sex-, and SES-matched healthy controls;

(ii) performance by TBI participants with moderate-severe injuries will be worse than performance by TBI participants with mild injuries.

Methods

Design and Setting

The current study used a quasi-experimental design to (a) assess differences in neuropsychological test performance of TBI children compared to healthy controls, and (b) examine whether injury severity was a significant predictor of neuropsychological outcome in this South African pTBI sample. The study took place in the city of Cape Town and surrounding communities

Participants

TBI participants: Initial identification. The initial pool of potential participants was identified from the RXH trauma register dated 2007 to 2009. After the trauma register had been used to identify children who had sustained a TBI, folder numbers for those individuals were retrieved from the same register, and the folders were extracted from the hospital's Medical Records department. With the folders in hand, I was able to determine whether each potential participant described by the medical record met the study's inclusion criteria.

TBI participants: Inclusion and exclusion criteria. The following criteria were used to determine whether potential participants, identified as described above, would be included in the study: documented presence of a TBI (following the medical record); age between 7 and 10 years; 12-36 months post-injury; and fluency in English. Those criteria were set in place for these reasons: the age band and time post-injury were restricted so as to minimize variability in neuropsychological test performance attributed to these variables. Furthermore, previous literature suggests that cognitive deficits following TBI typically reach a plateau at 12 months post-injury (Anderson et al., 2001; Faye et al., 2009). Finally, only English-fluent children were included in the final sample as only English versions of the tests in the current battery exist.

TBI severity for each participant was based on Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974) scores upon admission to the RXH Trauma Ward. Following conventional criteria, mild TBI was defined as a GCS score of 13-15, and moderate-severe TBI as a GCS score of 3-12.

Potential participants were excluded from participation in the study if they (a) had a previous history of TBI (other than the current injury), or (b) presented with co-morbid mental retardation, learning disabilities, epilepsy, or attention-deficit/hyperactivity disorder (ADHD).

After potential participants meeting these inclusion and exclusion criteria were identified and their contact details recorded, parents/guardians were telephoned to enquire about their interest in volunteering for the study. During this conversation, parents/guardians were informed about the purpose and nature of the study (e.g., the number and duration of assessment sessions), and the fact that confidentiality would be maintained throughout the study. Once confirmation of participation

was given, an appointment was made and parents/guardians were told they would receive reimbursement for travel costs.

During the recruitment process, contact details that were outdated greatly reduced the pool of participants the study could utilize. Of the initial 257 possible candidates identified from the RXH hospital records, only 50 were contactable. Of the candidates who were contacted, 1 was excluded due to a diagnosis of ADHD, 2 declined participation, and 2 did not arrive for testing after agreeing to participate and being scheduled for an appointment. Furthermore, 18 were at telephone numbers that were current, but the researcher was never able to speak to the parents/guardians directly. In the mild injury group, 3 participants were dropped to ensure equal group sizes (see Appendix A).

Table 1 presents demographic and clinical characteristics of participants who comprised the final sample of TBI children. There were no statistically significant differences with regard to time since injury between the mild and moderate-severe TBI groups, $t(22) = 1.19$, $p = 0.835$. Of further interest with regard to the data presented for TBI participants is the trend in the etiology of injury: most moderate-severe TBIs were attributable to MVAs, whereas all injuries related to falls were found in the mild TBI group. This trend is consistent with that reported in previously published research, which shows that falls and MVAs are the main causes of TBI, and that more severe injuries are most frequently due to involvement in MVAs (De Villiers et al., 1984; Hawley et al., 2003; Lalloo & van As, 2004; Semple et al., 1998).

Table 1
Demographic and Clinical Characteristics of the Sample

Variable	TBI		Control
	Mild	Mod-severe	
	(*n* = 12)	(*n* = 12)	(*n* = 24)
Sex (males:females)	8:4	12:0	19:5
Age (years)	8.23 (1.10)	8.47 (0.91)	8.48 (1.09)
Time post-injury (months)	18.08 (6.14)	21.17 (6.55)	---
Race			
Coloured	11	11	14
Black	0	0	10
White	0	1	0
Indian	1	0	0
Home language			
English	10	5	8
Afrikaans	2	7	6
Zulu	0	0	1
Xhosa	0	0	9
Level of education			
Grade 1	1	3	1
Grade 2	4	2	11
Grade 3	3	4	3
Grade 4	3	3	9
Grade 5	1	0	0
Etiology of injury			
Falls	9	0	---
MVA passenger	1	4	---
MVA pedestrian	1	6	---
Bumped head	1	0	---
Blunt object to the head	0	2	---

Note. For the variables *Age* and *Time post-injury*, means are presented with standard deviations in parentheses.

Controls: Recruitment. Non-injured, typically developing control participants were recruited from a primary school in Cape Town. Possible participants were identified with the help of teachers. Consent forms were sent to the parents of these children, and only those whose consent forms were signed and returned were included in the study. Using these procedures, we recruited a sample of 24 children between the ages of 7 and 10 years, all of whom came from a low socio-economic status background, and all of whom were fluent in English. In order to ensure that all participants were healthy, normally developing children, teachers were asked to provide information with regards to the children's academic performance and whether any learning

difficulties were apparent. The control group comprised only those children whose teachers reported normal scholastic achievement.

Final sample. As Table 1 shows, the final sample was comprised of the following three groups: 12 children in the mild TBI group, 12 in the moderate-severe TBI group, and 24 children in the control group. There were no statistically significant differences between the groups in terms of age, $F(2, 45) = 0.824$, $p = 0.445$, or in terms of distribution of males and females within the groups, $\chi^2(2) = 4.667$, $p = 0.097$. Furthermore, all the children in the TBI group were recruited from RXH, which provides health care to children from low SES communities. The total monthly incomes of the parents were checked in the hospital folders to ensure that the children were indeed from such communities. Control participants were recruited from a government school in a community of a similarly low SES. This school was identified by the Western Cape Education Department (WCED) as one that provides tuition for low-SES families only. Therefore, the groups were successfully matched for age, sex, and SES.

There were also no statistically significant between-group differences in terms of level of education, $\chi^2(8) = 10.741$, $p = 0.217$. However, there were statistically significant between-group differences in terms of race and home language distribution, $\chi^2(6) = 17.778$, $p = 0.007$ and $\chi^2(6) = 18.238$, $p = 0.006$, respectively. These differences should not have affected the results of this study, however, as race and home language have not been found to be predictors of outcomes following pTBI (Anderson et al., 2001; Yeates et al., 2002). The distribution of race has only been shown to be an important factor when investigating the etiology of pTBI, which is not being assessed in the present study. Home language, on the other hand, could potentially have affected neuropsychological test performance as the current sample is culturally and linguistically different from the population on which the present test battery was normed. For instance, words (as used for test stimuli or as used in test instructions) may not have the same meanings or may be understood differently across different cultures (Ardila & Roselli, 2007; Nell, 2000; Uzzell, 2007). However, I controlled for this language factor by including in my sample only those children who self-reported themselves as being, and whose parents reported them to be, fluent in English.

Measures

A battery of standardized neuropsychological measures, featuring instruments that have been tested and normed in the UK, the US, and Australia, was used in this research. Table 2 presents a summary description of the battery.

Test of general intellectual functioning. The Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) was used to provide an estimate of IQ. This instrument was standardized and

normed in the United States, and is designed for use in individuals aged 6- 89 years. In the current research, Verbal IQ (VIQ) and Performance IQ (PIQ) were obtained for all participants.

Table 2
Neuropsychological Test Battery Used in the Current Study

Test name	Subtest name	Cognitive domain assessed
WASI		
Verbal IQ	Vocabulary	General intellectual functioning (verbal)
	Similarities	General intellectual functioning (verbal)
Performance IQ	Block Design	General intellectual functioning (non-verbal)
	Matrix Reasoning	General intellectual functioning (non-verbal)
TEA-Ch	Sky Search	Attention (selective/focused)
	Score!	Attention (sustained)
	Creature Counting	Attention (switching)
	Sky Search DT	Attention (sustained-divided)
CMS	Word Lists	Memory (verbal)
	Dot Locations	Memory (visual)
RCFT	30-min Delayed recall	Memory (visual)
NEPSY-II	Design Fluency	Executive functioning (generativity)
	Inhibition	Executive functioning (inhibition)
CMS	Numbers	Executive functioning (working memory)

Note. WASI = Wechsler Abbreviated Scale of Intelligence; TEA-Ch = Test of Everyday Attention for Children; CMS = Children's Memory Scale; RCFT = Rey Complex Figure Test.

The measure of VIQ is derived from scores on the Vocabulary and Similarities subtests. The *Vocabulary* subtest consists of 42 items. Items 1-4 require the naming of pictures that are displayed one at a time. For each of items 5-42, a word is presented visually and orally, and the examinee is required to define that word orally. This subtest is a measure of expressive vocabulary, verbal knowledge, and fund of information. It is also a comprehensive measure of crystallized intelligence and general intelligence (*g*; Wechsler, 1999).

The *Similarities* subtest consists of 26 items. On each of items 1-4, the examinee is presented with a picture of three common objects in a row at the top of a page, and pictures of four response possibilities in a row at the bottom of the same page. The examinee must point to the response option that is most similar to the set of three target objects. On each of items 5-22, the examinee is orally presented with a pair of words, each representing some common object or concept, and is required to explain the similarity between those words. This subtest is a measure of verbal concept formation, abstract verbal reasoning ability, and general intelligence (*g*) (Wechsler, 1999).

The *measure* of PIQ is derived from scores on the Block Design and Matrix Reasoning subtests. The *Block Design* subtest consists of a set of 13 modelled or printed two-dimensional geometric patterns that the examinee has to replicate within a specified time limit using two-colour

(white and red) blocks. This subtest taps abilities for spatial visualization, visual-motor coordination, perceptual organization, and abstract conceptualization (Wechsler, 1999).

The *Matrix Reasoning* subtest features a series of 35 incomplete gridded patterns that the examinee is required to complete by pointing to or stating the number of the correct response from five possible choices. Performance on this subtest is indicative of the examinee's ability to mentally manipulate and perceive relationships among abstract symbols. It is a measure of nonverbal fluid reasoning (Wechsler, 1999).

The WASI administration and scoring manual reports that test-retest reliability coefficients range from .86 to .93 for Vocabulary, from .81 to .91 for Similarities, from.86 to .93 for Block Design, and from .86 to .96 for Matrix Reasoning. For both VIQ and PIQ the reliability coefficient ranges from .92 to .95. The test developers ensured content validity through a systematic content analysis of similar subtests on other Wechsler test batteries, and through a review of parallel items in terms of their similarity to related items on those other batteries. Construct validity is supported by the intercorrelations of scores on the WASI subtests and other IQ tests, and by the results of factor analyses that showed that a two-factor model (two Verbal subtests and two Performance subtests) demonstrates best fit for the data from the normative children's sample (6 to16 years), normative adult sample (17 to 89 years), the total normative sample, and across all six normative age bands (6-9, 10-13, 14-16, 17-34, 35-69, and 70-89) (Wechsler, 1999).

Test of attention. The Test of Everyday Attention for Children (TEA-Ch; Manly et al., 1999) was used as a measure of attention. This instrument has been standardized and normed in Australia for children and adolescents between the ages of 6 and 16 years. The battery consists of nine subtests; this study, however, employed a briefer screening version, using only the first four subtests. Reliability of the nine subtests is reportedly high, with coefficients ranging from .57 to .87, and strong inter-correlations. Validity is also good, with high regression coefficients with CFI (Comparative Fit Index) = .937; NFI (Normed Fit Index) = .913; and NNFI (Non-Normed Fit Index) = .96, all well above the fit index value of 0.9 (Manly et al., 1999). These statistics indicate that the three main constructs measured by the TEA-Ch (selective attention, attentional control/switching, and sustained attention) form a good fit for observed patterns of performance.

The *Sky* Search subtest of the TEA-Ch is a short timed test that measures selective/focused attention. In the first part of the task, children have to find as many target spaceships as possible on a sheet filled with similar distractor spaceships. In the second part, there are no distractors. Subtracting the score on part 1 from that on part 2 gives a measure of the child's ability to make a selection that is relatively free from the influence of motor slowness.

The *Score!* subtest of the TEA-Ch measures sustained attention. Here, children have to keep count of a number of scoring sounds they hear on a tape as if they are keeping the score on a

computer game. Because this seems such a simple task and due to the long intervals between the sounds, this task does very little to grab the child's attention. For this reason it is a good test of the child's ability to sustain his/her own attention.

The Creature *Counting* subtest of the TEA-Ch measures attentional switching. In this subtest, the child must repeatedly switch between two simple tasks (counting upwards and counting downwards). Time taken and accuracy are scored.

The *Sky Search DT* subtest of the TEA-Ch measures sustained-divided attention. After having completed the Sky Search and Score! subtests, the child is asked to combine the two activities (finding the spaceships and keeping count of scoring sounds) and to perform them simultaneously.

Test of memory. The Children's Memory Scale (CMS; Cohen, 1997) was the primary battery used for the measurement of memory. This battery was normed and standardized in the US for children and adolescents between the ages of 5 and 16 years. The test developer reports that reliability coefficients for the core subtests of the battery range from .61 to .93 and from .65 to .93 for the supplemental subtests. Regarding content validity, the CMS appears to provide a comprehensive assessment of memory and learning abilities in children aged 5 to 16 years. Content validity was established as follows: After construction of a trial version of the test, a panel of experts reviewed the battery and eliminated some subtests based on factors such as redundancy, ease of administration and scoring, and "child-friendliness". After a national standardization tryout, the remaining subtests were re-evaluated and some were then eliminated based on content, bias, and psychometric properties. Pearson correlation coefficients for the remaining subtests ranged from .06 to .96 across all ages, providing support for the structure and construct validity of this test. Regarding criterion-related validity, *t*-test analyses within studies of special groups (epilepsy, TBI, and brain tumours) showed that participants drawn from clinical populations performed more poorly than demographically-matched controls on CMS indexes.

Three CMS subtests were used in this study. The CMS *Word Lists* subtest was used to measure verbal memory. Specifically, this subtest assesses the child's ability to learn a list of unrelated words over 4 learning trials. In the immediate recall portion of the test, after the child has been initially presented with the list and asked to recall it, he/she is reminded of only those words that were not recalled. This is followed by a single presentation and recall of a distractor word list, and then free recall of the first list again. In the delayed portion, the child is asked to provide the original word list from memory. After the delayed recall task, a list of words is read to the child from which he/she must identify those words that he/she was asked to remember earlier.

The CMS *Dot Locations* subtest was used to measure visual memory. Specifically, this subtest assesses the child's ability to learn the spatial location of an array of dots over 3 learning

trials. In the immediate recall section of the test, presentation and recall of the learning trials are followed by a single presentation and recall of a distractor array, then recall of the first dot array again. In the delayed recall portion, the child is asked to recall the array presented earlier.

The Rey Complex Figure Test (RCFT; Osterrieth, 1944)) was also used as a measure of visual memory. This test, which has been normed and standardized in Canada for individuals from ages 6 to 85 years (Meyers & Meyers, 1995), is essentially a drawing and visual memory test that assesses the ability to copy a complex figure and remember it for later recall. Poulton and Moffitt (1994) measured construct validity in a non-clinical population by administering the RCFT to 740 normally developing children, all aged approximately 13 years. They found that performance on the RCFT was closely correlated to that on the Block Design and Object Assembly subtests of the Weschler Intelligence Scale for Children-Revised (WISC-R; Wechsler, 1974). Internal and interrater consistency reliabilities were demonstrated by computing the reliability coefficients for the Boston Qualitative Scoring System (BQSS; Stern et al., 1994) used for scoring the RCFT. The BQSS is comprehensive in that it assesses both visuospatial abilities and qualitative features of the figure drawing. Internal consistency reliability coefficients ranged from 0.7774 to 0.9128, with inter-rater reliability coefficients ranging from 0.6342 to 0.9919.

Test of executive functioning. Two subtests from the NEPSY-II battery (Korkman, Kirk, & Kemp, 2007) and one subtest from the CMS were used to assess executive functioning.

The NEPSY-II was normed and standardized in the US for children and adolescents aged 7-16 years. The test developers report that reliability of the subtests contained in the battery was measured by means of inter-rater and interscores agreement, subtest internal consistency, and test-retest stability. Stability coefficients ranged from .62 to .89, providing support for this test's stability across time and age groups. Data for content validity were obtained from test performance of normally developing children, as well as from clinical studies in which the effectiveness of the NEPSY-II in distinguishing healthy children from those with known neurodevelopmental disorders (including learning disabilities, attention deficit/hyperactivity disorder, TBI, autistic disorders, and speech and learning impairment) was established. Construct validity was established through concurrent validity studies with other measures and clinical group studies (Korkman et al., 2007).

The NEPSY-II Design Fluency subtest assessed the child's behavioural productivity. The test requires the child to generate unique designs by connecting up to five dots that are presented in a structured and random array. The child must draw as many designs as he or she can on each array within a specified time limit.

The NEPSY-II *Inhibition* subtest assessed the child's ability to (a) inhibit automatic responses in favour of new responses, and (b) switch between response types. The child is required to look at a series of black and white shapes or arrows. The subtest is divided into naming,

inhibition, and switching tasks. In the naming task, the child is required to simply provide the name of the shape or say the direction in which the arrow is pointing. In the inhibition task, he/she must say the opposite name of the shape or direction of the arrow; for example, a circle becomes a square and an upward-pointing arrow becomes down. Finally, in the switching task the child must provide the opposite name or direction depending on the colour of the shape or arrow. For instance, the correct response to the presentation of a white square is “circle”, whereas the correct response to a black square remains “square”. Similarly, the correct response to a white arrow pointing upwards is “down”, whereas the correct response to a black arrow pointing downwards remains “down”.

The CMS *Numbers* subtest was used to assess working memory. This subtest measures the child’s ability to repeat random digit sequences of graduated length. In the forward portion, the child is asked to repeat the digits in the same sequence as was orally presented by the examiner. In the backward portion, the child is asked to repeat the digits in the reverse order of the presentation.

Procedure

Confirmation calls were made a day before each testing session. Each participant was individually tested in one session lasting 180-240 minutes. At the beginning of the session, parents had the opportunity to ask any clarifying questions before filling in a consent form (see Appendix B). In the presence of parents/guardians, children were told about the types of tasks they would perform, that breaks were allowed, and that they could stop at any time during the process. After these explanations, the child was then given an assent form (see Appendix C) to sign. Parents were also told that they could observe the session if they so chose. Before actual testing began, parents were administered a developmental questionnaire (see Appendix D) in order to help the examiner to identify any pre-existing developmental issues. Reliance on this method alone can produce a distorted picture of the child’s abilities, however (Anderson et al., 2001). Therefore, a school report form describing scholastic performance (see Appendix E) was sent to the child’s teacher after obtaining parental consent so as to obtain a more comprehensive representation of abilities.

Testing occurred at one of two dedicated rooms at RXH or in a laboratory in Department of Psychology at UCT. In instances where parents were unable to come to the testing venue, the researcher went to their homes to conduct the assessment.

At the beginning of the assessment, children were given a star chart (see Appendix F) on which they put a star upon completion of each task. At the end of the testing session children were given a reward of sweets. Where traveling to the testing venue was involved, parents were reimbursed R50 to cover traveling costs.

Statistical Analysis

Before actual analyses were performed, data were checked and cleaned. The raw scores obtained on the measures were converted to age-appropriate scaled scores following conventional procedures outlined in the various test manuals. Descriptive statistics were compiled using Statistica 9.0 (Statsoft, 2009) and PASW Statistics (SPSS, 2010), and were employed to explore the data and establish whether any trends existed. Inferential analyses were conducted using the same statistical software packages. A statistical significance level of $p = 0.05$ was used and effect size estimates were reported where appropriate; these estimates allow for assessment of real-world significance of group differences.

One-way ANOVA was used to assess for significant age differences between the two TBI groups and the control group, and a two-tailed *t*-test was used to assess for significant differences in time since injury between the mild and moderate-severe TBI groups. Chi-squared (χ^2) analysis was used to investigate differences in sex distribution across the three groups.

Outcome variables. To understand the analyses employed and precisely what each outcome variable entails, a brief explanation of which scores were generated by each subtest is needed. All scoring procedures followed those outlined in the relevant test manuals; reliability and fidelity were ensured by having two members of our research team check each test protocol.

VIQ and PIQ. Age-adjusted scaled scores for each of the WASI Vocabulary and Similarities subtests were combined, and the combination was used to measure the child's general verbal abilities via the VIQ index score. Similarly, age-adjusted scaled scores for each of the WASI Block Design and Matrix Reasoning subtests were combined, and the combination was used to measure the child's general non-verbal abilities via the PIQ index score.

Selective/focused attention. To assess the ability to focus attention on the task at hand, I calculated age-adjusted scaled scores for the following: (a) the TEA-Ch Sky Search Targets score, which was the number of correctly identified targets found on the first target sheet, (b) the Sky Search Time per Target score, which was the total time taken (in seconds) divided by the number of correctly identified targets found on the first target sheet (Sky Search Targets score), (c) and the Sky Search Attention score, which was the Sky Search Time per Target score minus the Sky Search Motor Control Time per Target Score (the total time taken divided by the number of targets found on the second, motor control, target sheet)

Sustained attention. To assess the ability to sustain attention over time, I calculated age-adjusted scaled scores representing the accuracy of the child's count of relevant sounds on the TEA-Ch Score! subtest. This score was obtained by adding all the correct items on the scoring sheet.

Sustained/divided attention. To assess the ability to simultaneously sustain attention and divide it between two competing stimuli, I calculated age-adjusted scale scores representing the

accuracy of the child's ability to count the relevant sounds on the scoring tape while simultaneously correctly identifying targets on the TEA-CH Sky Search DT target sheet. This score was represented by the Sky Search DT decrement score, which was calculated by subtracting the Sky Search Time per Target score (on the Sky Search subtest) from the Weighted Time per Target score on the Sky Search DT subtest.

Switching attention. A TEA-Ch Creature Counting score could not be calculated due to the fact that many children in the moderate-severe TBI group were unable to count upwards from 1 to 15 and backwards from 15 to 1: The TEA-Ch manual states that the test not be administered to children who do not meet this counting ability. For this reason, this subtest was dropped from the final analysis.

Verbal memory. To assess the ability to encode, store, and retrieve orally-presented information, I calculated CMS Word List learning, delayed recall, and delayed recognition age-adjusted scaled scores. The Word List learning score was calculated by adding the number of correct responses over the four learning trials. The Word List delayed recall score was obtained by adding the number of correct responses on the 25-minute delayed recall task. Finally, the Word Lists delayed recognition score was calculated by adding all the correct responses on the delayed recognition task that immediately followed the delayed recall task.

Visual memory. To assess the ability to encode, store, and retrieve visually-presented information, I calculated CMS Dot Locations learning, total, and delayed recall age-adjusted scaled scores. The Dot Locations learning score was obtained by adding the number of correct responses over the three learning trials. The Dot Locations total score was calculated by adding the learning score to the 5-minute short-delay recall score. The Dot Locations delayed recall score was calculated by adding the correct responses on the 25-minute delayed recall task. Furthermore, I scored the RCFT 30-minute delayed recall figure using conventional criteria outlined by Meyers and Meyers (1995), and used these raw scores in my final data analyses

Working memory. To assess the ability to acquire, hold, and manipulate bits of information, I calculated CMS Numbers Forward, Backward, and Total age-adjusted scaled scores. The Numbers Forward score represented the number of correct responses when repeating strings of numbers in the same order as read by the examiner. The Numbers Backward score represented the number of correct responses when repeating strings of numbers in the reverse order from that read by the examiner. The Numbers Total score was obtained by adding the Numbers Forward to the Numbers Backward score.

Executive functioning. To assess multiple aspects of executive functioning, including cognitive flexibility and the ability to inhibit automatic responses (or inhibitory control), I calculated age-adjusted scaled scores for each of the following NEPSY-II subtests. For the ability to

use flexible cognitive processes to produce novel designs, the Design Fluency score was calculated by adding the number of correct designs on the structured and random array design sheets. The Inhibition-Naming combined scaled score and the Inhibition-Naming completion time scaled score were obtained to ensure that poor performance was not due to language impairment. Inhibitory control was measured by obtaining the Inhibition-Inhibition combined scaled score and the Inhibition-Inhibition completion time scaled score. Finally, the Inhibition-Switching combined scaled score, and the Inhibition-Switching completion time scaled score, were generated for assessing the child's cognitive flexibility in switching between different response types. For all the Inhibition scores, the combined scaled scores integrated the total errors percentile rank with the completion time scaled score; the latter were calculated by adding the completion time for the shapes to the completion time for the arrows response sets.

Neuropsychological test battery performance. Analysis of performance by the participants in the three groups on the neuropsychological test battery was analyzed in two separate steps.

One-way analysis of variance. A series of one-way ANOVAs were conducted on each outcome variable to assess the relationship between group membership and performance on the cognitive process/domain assessed by that outcome variable. Two 2-group comparisons were made: the first between the combined TBI group and the control group, and second between the mild TBI group and moderate-severe TBI group. The reason for employing this method and not conducting one 3-group comparison is that this allows a more detailed assessment of differences between equal-*n* groups in terms of neuropsychological test performance. Finally, a conventional 3-group comparison was conducted to assess to which injury group (mild or moderate-severe TBI group) significant differences between the TBI and control group could be attributed. For those measures where the assumptions of homogeneity of variance and normality of data distribution were not upheld, non-parametric analyses, specifically the Mann-Whitney *U*-test, was employed.

Multiple regression analyses. For a more refined and powerful analysis of the relationship between group membership and neuropsychological test performance, a set of multiple hierarchical regression analyses were performed. Conducting these analyses helped to establish whether group membership could be predicted by neuropsychological test performance while controlling for age and sex differences.

In order to conduct the regression analyses, a set of cognitive domains was created from the relevant outcome measures. More specifically, the vast number of outcome variables originally assessed in this study was reduced by calculating composite neuropsychological scores. This was accomplished by employing a hybrid method of grouping the outcome measures (as described by Medina et al., 2007). This method involves grouping variables based on both (a) the theoretical

categories of cognitive domains (Lezak, Howieson, & Loring, 2004), and (b) results of item reliability analyses using Cronbach's alpha (α). This method ensured that each final composite domain category comprised outcome variables that were both statistically significantly correlated as well as theoretically associated.

The decision on which outcome measures should go together in each composite cognitive domain was based on, initially, grouping the measures together following theoretical assumptions surrounding what each measure assessed. Internal consistency for each grouping was then statistically assessed using Cronbach's α. This statistic was obtained by calculating (a) a *z*-score for each outcome measure based on the entire sample's (N = 48) scores, and (b) a correlation coefficient for all of the *z*-scores in each composite domain. Item reliability analyses were then conducted on the outcome measures comprising each category domain. The *z*-scores for each outcome measure within a particular composite domain were then averaged to give the final overall composite *z*-score for that domain.

Ethical considerations

Participation in this study did not involve any possible harmful effects to the children. The only negative impact associated with participation was the child tiring due to the long duration of the testing session. However, both the child and his/her parents were informed that breaks could be taken or that the session could be stopped at any time without any negative consequences for the child or his/her parents.

All study protocols were approved by the Research Ethics Committee of the UCT Faculty of Health Sciences, by the Research Ethics Committee of the UCT Department of Psychology, and by the WCED.

Results

Hypothesis 1

My first hypothesis was that children with TBI would perform significantly more poorly on the measures of cognitive functioning than age-, sex-, and SES-matched healthy controls.

ANOVA results. In order to test whether TBI participants performed significantly more poorly on measures of neuropsychological performance than matched healthy controls, I conducted a series of one-way ANOVAs, with group membership (TBI vs. control) always the between-subjects factor and individual neuropsychological test scores as the outcome measure. The assumption of normality was upheld for all of the datasets. However, Levene's test of homogeneity was violated for the Sky Search DT outcome variable (see Table 3). In this instance, the non-parametric Mann-Whitney *U*-test was used to assess for significant between-group differences.

Table 4 shows the results of all between-group comparisons. The series of ANOVAs showed that there were statistically significant between-group differences on the following measures: WASI Vocabulary, WASI Similarities, CMS Numbers Forward and Numbers Total, and NEPSY-II Design Fluency. The effect size estimate (Cohen's *d*) was in the range conventionally described as large for WASI Vocabulary and WASI Similarities, medium for CMS Numbers Forward and NEPSY-II Design Fluency, and small for CMS Numbers Total (Cohen, 1988).

The TBI group demonstrated a poorer performance than the control group on all statistically significant measures. Based on this analysis and these results, the cognitive functions most affected in the TBI group are verbal abilities including semantic knowledge and abstract semantic reasoning, attention and concentration abilities, and the ability to use flexible cognitive thought processes.

Table 3
Hypothesis 1: Levene's Test Results for the Neuropsychological Test Battery

Test and domain	Levene's *F*	Levene's *p*
WASI: Verbal IQ		
Vocabulary	0.115	0.736
Similarities	2.368	0.131
WASI: Performance IQ		
Block Design	3.091	0.085
Matrix Reasoning	0.766	0.386
TEA-Ch Sky Search: Selective attention		
Targets	3.535	0.074
Time per target	1.900	0.175
Attention	0.367	0.548
TEA-Ch Score!: Sustained attention	0.332	0.567
TEA-Ch Sky Search DT: Sustained/divided attention	4.467	0.040*
CMS Dot Locations: Visual memory		
Learning	0.565	0.456
Total	0.196	0.660
Delayed Recall	0.447	0.507
RCF 30-min delayed recall: Visual memory	0.390	0.536
CMS Word Lists: Verbal memory		
Learning	0.088	0.768
Delayed recall	1.079	0.305
Delayed recognition	0.845	0.364
CMS Numbers: Working memory		
Forward	0.125	0.725
Backward	1.380	0.246
Total	0.103	0.750
NEPSY-II: Executive functioning		
Design Fluency	0.044	0.835
Inhibition-Naming combined	0.211	0.648
Inhibition-Naming completion time	0.505	0.481
Inhibition-Inhibition combined	0.059	0.809
Inhibition-Inhibition completion time	0.295	0.590
Inhibition-Switching combined	0.867	0.357
Inhibition-Switching completion time	0.186	0.668

*$p < 0.05$.

Table 4
Hypothesis 1: Composite domains: Descriptive statistics and between-group comparisons

	TBI (n = 24)		Control (n = 24)				
Composite domain/Tests within domain	*M(SD)*	Range	*M(SD)*	Range	*F*	*p*	ESE
Verbal IQ (domain *z* scores)	**-0.44 (0.86)**	**-2.41 to 1.43**	**0.44 (0.68)**	**-0.75 to 1.71**			
WASI							
Vocabulary	5.08 (1.67)	1 to 9	6.46 (1.64)	3 to 10	8.30	0.006**	0.82
Similarities	6.63 (2.79)	2 to 11	9.46 (2.11)	5 to 12	15.74	<0.001***	1.13
Performance IQ (domain *z* scores)	**-0.01 (0.99)**	**-1.97 to 2.49**	**0.01 (0.65)**	**-1.13 to 1.14**			
WASI							
Block Design	7.92 (2.86)	3 to 17	7.50 (1.25)	6 to 10	0.43	0.516	0.19
Matrix Reasoning	7.33 (3.32)	2 to 14	8.00 (2.99)	3 to 13	0.53	0.469	0.21
Selective/focused attention (domain *z* scores)	**-0.28 (0.81)**	**-1.76 to 1.03**	**0.22 (0.49)**	**-0.71 to 1.11**			
CMS Numbers Forward	6.71 (3.20)	1 to 13	8.83 (3.07)	4 to 16	5.51	0.023*	0.67
TEA-Ch Sky Search							
Targets	8.43 (3.17)	3 to 14	9.58 (2.22)	6 to 14	2.08	0.156	0.41
Time per target	3.65 (2.81)	1 to 9	4.50 (2.28)	1 to 9	1.30	0.261	0.33
Attention	4.48 (3.36)	1 to 12	5.92 (3.59)	1 to 16	2.01	0.163	0.41
Sustained attention (domain *z* scores)	**-0.12 (1.12)**	**-2.30 to 1.63**	**0.02 (0.98)**	**-1.39 to 2.23**			
TEA-Ch Score!	7.55 (3.45)	2 to 13	7.67 (3.25)	3 to 15	0.02	0.903	0.04
Sustained/divided attention (domain *z* scores)	**-0.03 (0.86)**	**-0.92 to 1.98**	**0.18 (1.10)**	**-0.77 to 1.98**			
TEA-Ch Sky Search DT	4.73 (5.66)	1 to 19	7.21 (7.19)	1 to 19	1.70	0.203	0.38
Verbal memory (domain *z* scores)	**-0.24 (0.95)**	**-2.34 to 2.09**	**0.19 (0.91)**	**-1.14 to 1.88**			
CMS Word Lists							
Learning	8.05 (2.74)	1 to 14	9.29 (2.35)	5 to 14	2.55	0.188	0.48
Delayed recall	9.47 (2.27)	6 to 15	10.33 (2.41)	7 to 14	1.42	0.240	0.36

Composite domain/Tests within domain	TBI (*n* = 24) *M(SD)*	Range	Control (*n* = 24) *M(SD)*	Range	*F*	*p*	ESE
Visual Memory (domain *z* scores)	**-0.05 (0.85)**	**-2.47 to 1.34**	**0.05 (0.81)**	**-1.49 to 1.79**			
CMS Dot Locations							
Learning	9.75 (4.02)	1 to 18	10.00 (3.39)	3 to 14	0.05	0.817	0.07
Total	9.33 (3.32)	1 to 15	10.42 (3.37)	4 to 15	1.26	0.268	0.32
Delayed recall	9.29 (2.68)	2 to 14	10.21 (2.23)	6 to 14	1.66	0.204	0.37
RCF 30-min delayed recall	15.31 (6.35)	2 to 29	12.88 (7.60)	2.5 to 36	1.45	0.234	0.34
Working memory (domain *z* scores)	**-0.27 (0.94)**	**-1.94 to 1.42**	**0.27 (0.86)**	**-0.94 to 2.37**			
CMS Numbers							
Backward	7.04 (3.17)	2 to 13	8.29 (2.31)	5 to 13	2.44	0.125	0.44
Total	5.96 (2.94)	1 to 10	7.96 (3.16)	4 to 16	5.16	0.028*	0.65
Inhibition (domain *z* scores)	**-0.23 (0.94)**	**-1.91 to 2.17**	**0.16 (0.84)**	**-1.74 to 1.79**			
NEPSY-II Inhibition							
Inhibition-Inhibition combined	5.39 (3.03)	1 to 13	7.00 (3.21)	1 to 14	3.06	0.087	0.51
Inhibition-Inhibition completion time	8.09 (3.46)	2 to 19	9.04 (2.51)	3 to 13	1.15	0.289	0.31
Cognitive flexibility (domain *z* scores)	**-0.20 (0.89)**	**-0.20 to 1.42**	**0.10 (0.73)**	**-1.90 to 1.65**			
NEPSY-II Design Fluency	5.50 (2.70)	1 to 11	7.21 (2.70)	3 to 13	4.80	0.033*	0.62
NEPSY-II Inhibition							
Inhibition-Switching combined	3.95 (3.17)	1 to 14	6.33 (2.44)	1 to 12	0.21	0.652	0.83
Inhibition-Switching completion time	8.81 (3.01)	4 to 19	8.33 (2.76)	1 to 13	0.31	0.583	0.62

Note. Data presented are *z* scores (converted *z* scores based on the entire sample, $N = 48$) for composite domain categories and scaled scores (SS) for most individual outcome variables. Scaled scores are presented with the average performance and standard deviation in parentheses of each group's participants. For RCF 30-min Delayed Recall, raw scores are presented. ESE = Cohen's *d* is effect size estimate used in analyses.
*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

Regression results. Multiple regression was used as a more refined and powerful analysis of the relationship between group membership and neuropsychological test performance. It was also of interest to see whether this method confirmed the results obtained from the ANOVA analysis.

Composite domains. The hybrid method of grouping variables (as described above, and based on confirming theoretical categories of cognitive domains with the results of reliability analyses using Cronbach's α) resulted in the creation of 10 composite domain categories:

- verbal IQ ($\alpha = 0.73$)
- performance IQ ($\alpha = 0.54$)
- selective/focused attention ($\alpha = 0.58$)
- sustained attention[1]
- sustained/divided attention
- verbal memory ($\alpha = 0.80$)
- visual memory ($\alpha = 0.72$)
- working memory ($\alpha = 0.85$)
- inhibition ($\alpha = 0.73$)
- cognitive flexibility ($\alpha = 0.68$)

As can be seen, the Cronbach's α coefficient associated with each of these domains was larger than 0.50 (range = 0.54 to 0.85). All of the coefficients therefore fall within the acceptable range for α coefficients in reliability testing (Finchilescu, 2002). A brief outline of the outcome variables comprising each composite domain follows; descriptive statistics for each domain are shown in bold in Table 4.

The domain of verbal IQ was, not surprisingly, comprised of the WASI Vocabulary and Similarities subtests. Similarly, the domain of performance IQ was comprised of the WASI Block Design and Matrix Reasoning subtests.

With regard to attentional abilities, the domain of selective/focused attention was comprised of the outcome variables from the TEA-Ch Sky Search subtest (targets, time per target, and attention) and the CMS Numbers Forward subtest. Theoretically, Numbers Forward tests the child's ability to attend to or focus on the task at hand (Cohen, 1997); this was the basis for grouping this variable with the TEA-Ch Sky Search measures. The domain of sustained attention comprised a single outcome variable, that from the TEA-Ch Score! subtest. Similarly, the domain of sustained/divided attention comprised only a single outcome variable, that from the TEA-CH Sky Search DT subtest.

[1]Cronbach's α coefficients are not reported for the domains of sustained attention and sustained/divided attention as these domains comprised only one measure each.

With regard to memory abilities, the domain of working memory was comprised of outcome variables derived from CMS Numbers subtests (Backward and Forward+Backward total); the domain of verbal memory was comprised of outcome variables derived from the CMS Word Lists subtest (learning and delayed recall); and the domain of visual memory was comprised of outcome variables derived from the CMS Dot Locations subtest (learning, total, and delayed recall).

With regard to executive functioning abilities, the domain of inhibition was comprised of outcome variables derived from the NEPSY-II Inhibition subtest (Inhibition-Inhibition combined score and Inhibition-Inhibition completion time score). The domain of cognitive flexibility was comprised of three outcome variables derived from the NEPSY-II: Design Fluency total score, Inhibition-Switching combined score, and Inhibition-Switching completion time score. The Design Fluency and Inhibition-Switching subtests were grouped together due to the underlying theoretical assumption that low scores on these subtests suggest difficulty with cognitive flexibility (Korkman et al., 2007). On the Design Fluency subtest, poor cognitive flexibility is evident when the child has difficulty engaging in problem-solving behaviour and producing novel designs. In the case of the Inhibition subtest, cognitive flexibility is needed in the switching condition when the child has to switch back and forth between inhibitory and naming tasks.

Excluded outcome variables. Following the theoretical basis and the domains of interest in this study, the RCF Copy, NEPSY-II Inhibition Naming combined and NEPSY-II Inhibition-Naming completion time variables were excluded from further analysis. Because the two NEPSY-II variables mentioned above are measures of processing speed while accomplishing a simple naming task (Korkman et al., 2007), there was no theoretical basis for grouping these measures into one of the executive function domains (inhibition or cognitive flexibility). Similarly, the RCF Copy, when scored using conventional criteria, is a measure of visuoconstructional ability, which is not one of the domains of interest here.

Primary multiple regression analyses. A separate multiple regression analysis, using group membership, age, and sex as hierarchically entered predictor variables and the domain *z*-score as an outcome variable, was conducted for each composite domain. That is to say, 10 separate regression analyses sought to determine whether group membership predicted performance within the defined domains.

All assumptions for regression analysis (normality, linearity, and homoscedasticity) were met for each domain. For each analysis, group membership was entered at the first step, age was entered at the second step, and sex was entered at the third step.

As shown in Table 5, the overall regression models were significant only for the domains of verbal IQ and selective/focused attention. The beta values (standardized correlation coefficients) derived from these analyses suggested that group membership, specifically, was a statistically

significant predictor of neuropsychological performance in these domains, even when age and sex differences were controlled for (i.e., participants in the control group performed better than those in the TBI group).

Verbal IQ. As shown in Table 6, the regression analysis on the verbal IQ data indicated that group membership was a statistically significant predictor of performance, with participants in the control group doing better than those in the TBI group, even when age and sex were controlled for. Furthermore, the analysis showed that neither age nor sex was a significant predictor of performance in this domain.

As Table 6 also shows, group membership alone accounted for 24% of variability in performance in the domain of verbal IQ. The overall regression model, with group membership, age, and sex included, also explained 24% of the variability in verbal IQ performance and was a statistically significant fit for the data (see Table 5).

Table 5
Hypothesis 1: Primary regression model for all cognitive domains

	Cognitive domain									
	IQ		Attention				Memory		Executive function	
	Verbal	Performance	Selective/ focused	Sustained	Sustained/ divided	Visual	Verbal	Working	Inhibition	Cognitive flexibility
β: TBI vs. Control	0.494	0.004	0.338	0.068	0.195	0.064	0.221	0.283	0.218	0.171
Model $F(1, 44)$	5.906	0.103	3.627	0.100	1.549	0.532	1.557	1.497	1.070	0.841
Model p-level	0.002**	0.958	0.020*	0.959	0.216	0.663	0.215	0.228	0.372	0.479
Step 1 R^2	0.238	0.022	0.109	0.018	0.022	0.018	0.028	0.064	0.025	0.012
Step 2 R^2	0.221	0.043	0.160	0.041	0.056	0.025	0.015	0.052	0.022	0.012
Step 2 ΔR^2	< 0.001	0.001	0.068	0.000	0.054	0.015	0.011	0.008	0.019	0.021
Step 3 R^2	0.238	0.061	0.144	0.062	0.035	0.031	0.38	0.031	0.005	0.010
Step 3 ΔR^2	0.033	0.006	0.003	0.003	< 0.001	0.016	0.045	< 0.001	0.005	< 0.001

*$p < 0.05$. ** $p < 0.01$.

Table 6
Hypothesis 1: Regression analysis results for verbal IQ composite domain

	β	*t*	*P*
Step 1			
Constant		-3.753	< .001***
Group: TBI vs. Control	0.504	3.914	< .001***
Step 2			
Constant		-1.240	.221
Group: TBI vs. Control	0.505	3.914	< .001***
Age	-0.017	-0.129	.898
Step 3			
Constant		-1.725	.092
Group: TBI vs. Control	0.494	3.865	< .001***
Age	0.004	0.034	.973
Sex	0.183	1.425	.161

Note. For Step 1, $R^2 = 0.24$; for Step 2, $R^2 = 0.22$, and ΔR^2 for Step 2 < 0.001; for Step 3, $R^2 = 0.24$, and ΔR^2 for Step 3 = 0.03.
***$p < .001$.

Selective/focused attention. As shown in Table 7, the regression analysis on the selective/focused attention data indicated that group membership was a statistically significant predictor of performance, with participants in the control group doing better than those in the TBI group, even when age and sex were controlled for. Furthermore, the analysis showed that neither age nor sex was a significant predictor of performance in this domain.

As Table 7 also shows, group membership alone accounted for 11% of variability in performance in the domain of selective/focused attention. The overall regression model, with group membership, age, and sex included, explained 14% of the variability in selective/focused attention performance, and was a statistically significant fit for the data (see Table 5).

Table 7
Hypothesis 1: Regression analysis results for selective/focused attention composite domain

	β	*t*	*p*
Step 1			
Constant		-2.552	0.014*
Group: TBI vs. Control	0.357	2.595	0.013*
Step 2			
Constant		-2.772	0.008
Group: TBI vs. Control	0.342	2.550	0.014*
Age	0.261	1.945	0.058
Step 3			
Constant		-2.671	0.011*
Group: TBI vs. Control	0.338	2.497	0.016*
Age	0.267	1.960	0.056
Sex	0.054	0.398	0.693

Note. For Step 1, $R^2 = 0.11$; for Step 2, $R^2 = 0.16$ and ΔR^2 for Step 2 = 0.068; for Step3, $R^2 = 0.14$ and ΔR^2 for Step 3 = 0.003.
*$p < 0.05$.

Post-hoc multiple regression analyses. These follow-up analyses were performed only on the individual subtests that comprised the domains within which statistically significant between-group differences had been detected by the primary regression analyses. Again, the *z*-score of each outcome measure was used as the dependent variable, with group membership, age, and sex used as predictor variables.

Verbal IQ subtests. The individual outcome measures comprising this domain were scaled scores from the WASI Vocabulary and Similarities subtests.

As Table 8 shows, the overall models indicated that group membership was a statistically significant predictor of performance on both the Vocabulary and Similarities subtests. Table 9 shows more details of the hierarchical regression models fitted to the data from both subtests. As the table shows, when age and sex were held constant, group membership was statistically significantly associated with performance on both Vocabulary and Similarities, with participants in the control group doing better than those in the TBI group in both cases. Neither age nor sex were statistically significant predictors of performance on either subtest.

Table 9 also shows that group membership alone accounted for 13% of the variability in performance on the Vocabulary subtest and 24% of the variability in performance on the Similarities subtest. The overall regression model with group membership, age, and sex included accounted for 14% of variability in performance on the Vocabulary subtest and 31% of the variability in performance on the Similarities subtest. Both models were a significant fit for the data (see Table 8).

Finally, two regression equations were constructed for the prediction of group membership by neuropsychological test scores: Vocabulary: Group = -2.383 + 0.199 (age) + 0.095(sex) + 0.374; Similarities: Group = -0.565 – 1.563 (age) + 1.883 (sex) + 4.146.

Table 8
Hypothesis 1: Post hoc regression model results for each verbal IQ outcome measure

Outcome Measure			Step 1	Step 2		Step 3	
	$F(1, 44)$	p	R^2	R^2	ΔR^2	R^2	ΔR^2
WASI Vocabulary[a]	3.595	.021*	0.134	0.152	0.035	0.142	0.009
WASI Similarities[a]	8.039	< .001***	0.239	0.271	0.047	0.310	0.052

[a]Group membership significant in this outcome measure.
*p < .05. **p < .01. ***p < .001

Table 9
Hypothesis 1: Post-hoc regression analyses results for significant individual outcome measures in the verbal IQ composite domain

	WASI Vocabulary			WASI Similarities		
	β	t	p	β	t	p
Step 1						
Constant		-2.733	0.009**		-3.763	< .001***
Group: TBI vs. Control	0.391	2.880	0.006**	0.505	3.967	< .001***
Step 2						
Constant		-2.310	0.026*		0.213	0.833
Group: TBI vs. Control	0.379	2.820	0.007**	0.518	4.152	< .001***
Age	0.188	1.396	0.170	-0.217	-1.742	0.088
Step 3						
Constant		-2.383	0.022*		-0.565	0.575
Group: TBI vs. Control	0.374	2.756	0.008**	0.504	4.146	< .001***
Age	0.199	1.459	0.152	-0.191	-1.563	0.125
Sex	0.095	0.698	0.489	0.230	1.883	0.066

Note. For Vocabulary, Step 1, R^2 = 0.13; for Step 2, R^2 = 0.15 and ΔR^2 = 0.04; for Step3, R^2 = 0.14 and ΔR^2 = 0.01. For Similarities, Step 1, R^2 = 0.24; for Step 2, R^2 = 0.27 and ΔR^2 = 0.05; for Step 3, R^2 = 0.31 and ΔR^2 = 0.05.
*p < .05. ** p < .01. ***p < .001.

Selective/focused attention measures. The individual outcome measures comprising this domain were the CMS Numbers Forward subtest and the TEA-Ch Sky Search targets, time per target, and attention outcome variables.

As Table 10 shows, the overall models indicated that group membership was a statistically significant predictor of performance on the Numbers Forward subtest. Table 11 shows more details of the hierarchical regression models fitted to the data from the subtest. As the table shows, when age and sex were held constant, group membership was statistically significantly associated with performance on Numbers Forward, with participants in the control group doing better than those in

the TBI group. Neither age nor sex were statistically significant predictors of performance on this subtest.

Table 11 also shows that group membership alone accounted for 9% of the variability in performance on the Numbers Forward subtest. The overall regression model with group membership, age, and sex included accounted for 12% of variability in performance on the Numbers Forward subtest and was a statistically significant fit for the data (see Table 10).

Table 10
Hypothesis 1: Post-hoc regression model results for each selective/focused attention outcome measure

			Step 1	Step 2		Step 3	
Outcome Measure	$F(1, 44)$	p	R^2	R^2	ΔR^2	R^2	ΔR^2
CMS Numbers[a]	3.106	0.036*	0.088	0.117	0.048	0.119	0.020
TEA-Ch Sky Search							
Targets[b]	3.683	0.019*	0.042	0.165	0.138	0.146	< 0.001
Time per target	0.977	0.412	0.017	0.018	0.022	0.001	0.002
Attention	0.862	0.468	0.033	0.013	0.001	0.009	0.001

[a]Group membership significant in this outcome measure.
[b]Age significant in this outcome measure.
*$p < .05$.

Table 11
Hypothesis 1: Post-hoc regression analyses results for significant individual outcome measures in the domain of selective/focused attention

	CMS Numbers Forward			TEA-Ch Sky Search Targets		
	β	t	p	B	t	p
Step 1						
Constant		-2.227	0.031*		-1.803	0.078
Group: TBI vs. Control	0.327	2.348	0.023*	0.250	1.754	0.086
Step 2						
Constant		-2.314	0.025*		-3.301	0.002**
Group: TBI vs. Control	0.314	2.285	0.027*	0.228	1.706	0.095
Age	0.219	1.596	0.118	0.372	2.788	0.008**
Step 3						
Constant		-2.535	0.015*		-2.991	0.005**
Group: TBI vs. Control	0.305	2.220	0.032*	0.228	1.683	0.100
Age	0.235	1.705	0.095	0.372	2.740	0.009**
Sex	0.142	1.031	0.308	0.003	0.019	0.985

Note. For CMS Numbers Forward, Step 1, $R^2 = 0.09$; for Step 2, $R^2 = 0.12$ and $\Delta R^2 = 0.05$; for Step 3, $R^2 = 0.12$ and $\Delta R^2 = 0.02$. For TEA-Ch Sky Search Targets, Step 1, $R^2 = 0.04$; for Step 2, $R^2 = 0.17$ and $\Delta R^2 = 0.14$; for Step 3, $R^2 = 0.15$ and $\Delta R^2 < 0.001$.
*$p < .05$, ** $p < .01$

As Table 10 shows, the overall models indicated that age at the time of injury was a significant predictor on the TEA-Ch Sky Search Targets subtest. Table 11 shows each step of the hierarchical regression models fitted to the data from the subtest. As the table shows, when group

membership and sex were held constant, age at the time of injury was statistically significantly associated with performance on Numbers Forward, with participants in the control group doing better than those in the TBI group. Neither group membership nor sex were statistically significant predictors of performance on this subtest.

Table 11 also shows that group membership alone accounted for 17% of the variability in performance on the Numbers Forward subtest. The overall regression model with group membership, age, and sex included accounted for 15% of variability in performance on the Numbers Forward subtest and was a statistically significant fit for the data (see Table 10)

Finally, two regression equations were constructed for the prediction of group membership by neuropsychological test scores: CMS Numbers Forward: Group = -2.535 + 0.235 (age) – 0.142 (sex) + 0.305; Sky Search Targets: Age at injury = -2.991 + 0.228 (group) + 0.003(sex) + 0.372.

Hypothesis 2

My second hypothesis was that children with moderate-severe TBI would perform significantly more poorly on the measures of cognitive functioning than age-, sex, and SES-matched children with mild TBI.

ANOVA results. In order to test whether moderate-severe TBI participants performed significantly more poorly on measures of neuropsychological performance than mild TBI participants, I first conducted a series of one-way ANOVAs, with group membership (mild vs. moderate) always the between-subjects factor and individual neuropsychological test scores as the outcome measure. The assumption of normality was upheld for all of the datasets. However, Levene's test of homogeneity was violated for CMS Numbers Backward and NEPSY-II Inhibition-Switching combined (see Table 12). In these instances, the non-parametric Mann-Whitney *U*-test was used to assess for significant between-group differences.

Table 12
Hypothesis 2: Levene's Test Results for the Neuropsychological Test Battery

Test and domain	Levene's *F*	Levene's *p*
WASI: Verbal IQ		
Vocabulary	1.932	0.178
Similarities	0.415	0.526
WASI: Performance IQ		
Block Design	0.072	0.790
Matrix Reasoning	0.488	0.492
TEA-Ch Sky Search: Selective attention		
Targets	0.000	0.987
Time per target	0.138	0.714
Attention	0.918	0.349
TEA-Ch Score!: Sustained attention	0.332	0.567
TEA-Ch Sky Search DT: Sustained/divided attention	0.038	0.847
CMS Dot Locations: Visual memory		
Learning	0.084	0.774
Total	0.743	0.398
Delayed Recall	0.017	0.896
RCF 30-min delayed recall: Visual memory	0.566	0.460
CMS Word Lists: Verbal memory		
Learning	3.469	0.080
Delayed recall	0.182	0.675
Delayed recognition	4.096	0.063
CMS Numbers: Working memory		
Forward	0.098	0.757
Backward	4.829	0.039*
Total	2.133	0.158
NEPSY-II: Executive functioning		
Design Fluency	0.449	0.510
Inhibition-Naming combined	0.414	0.527
Inhibition-Naming completion time	0.743	0.399
Inhibition-Inhibition combined	0.625	0.438
Inhibition-Inhibition completion time	0.057	0.813
Inhibition-Switching combined	9.219	0.007**
Inhibition-Switching completion time	0.002	0.969

*$p < .05$. **$p < .01$.

Table 13 shows the results of all between-group comparisons. As can be seen, the series of ANOVAs showed that there were statistically significant between-group differences on the following measures: CMS Numbers Forward and Numbers Total, TEA-Ch Sky Search time per target, and NEPSY-II Design Fluency, Inhibition-Inhibition completion time, and Inhibition-

Switching completion time. On each of those between-group comparisons, the associated effect size estimates were in the range conventionally described as large (Cohen, 1988).

The data showed that participants in the moderate-severe TBI group performed more poorly than those in the mild TBI group on all statistically significant measures. Based on this analysis and these results, the cognitive functions most affected in the moderate-severe group appear to be the ability to focus attention, the ability to problem-solve using flexible cognitive processes, and the ability to inhibit automatic responses.

Table 13

Hypothesis 2: Composite domains: Descriptive statistics and between-group comparisons

	Mild TBI (n = 12)		Moderate-Severe TBI (n = 12)				
Composite domain/Tests within domain	*M(SD)*	Range	*M(SD)*	Range	*F*	*p*	ESE
Verbal IQ (domain *z* scores)	**-0.14 (0.65)**	**-0.05 to 1.43**	**-0.75 (0.97)**	**-0.05 to 0.69**			
WASI							
Vocabulary	5.67 (1.23)	4 to 9	4.50 (1.88)	1 to 8	3.23	.086	0.71
Similarities	7.42 (2.47)	2 to 11	5.83 (2.98)	2 to 11	2.01	.170	0.56
Performance IQ (domain *z* scores)	**0.38 (0.84)**	**-0.11 to 2.49**	**-0.39 (1.01)**	**-0.13 to 1.28**			
WASI							
Block Design	8.92 (2.91)	7 to 17	6.92 (2.54)	3 to 11	3.22	.086	0.71
Matrix Reasoning	8.33 (3.34)	3 to 14	6.33 (3.11)	2 to 13	2.30	.143	0.60
Selective/focused attention (domain *z* scores)	**0.06 (0.76)**	**-0.00 to 1.03**	**-0.62 (0.73)**	**-0.25 to 0.89**			
CMS Numbers Forward SS	8.42 (2.57)	5 to 13	5.00 (2.89)	1 to 10	9.34	.006**	1.21
TEA-Ch Sky Search							
Targets	8.08 (3.18)	3 to 13	8.82 (2.28)	4 to 14	0.30	.591	0.26
Time per target	4.75 (2.60)	1 to 8	2.45 (2.62)	1 to 9	4.44	.047*	0.85
Attention	5.67 (2.71)	1 to 9	3.18 (3.63)	1 to 12	3.51	.075	0.75
Sustained attention (domain *z* scores)	**0.29 (0.95)**	**-0.18 to 1.63**	**-0.57 (1.16)**	**-0.49 to 1.63**			
TEA-Ch Score!	8.58 (3.15)	4 to 13	6.30 (3.53)	2 to 13	2.57	.124	0.66
Sustained/divided attention (domain *z* scores)	**-0.09 (0.89)**	**-0.46 to 1.98**	**-0.38 (0.83)**	**-0.00 to 1.98**			
TEA-Ch Sky Search DT	5.42 (5.84)	1 to 19	3.90 (5.63)	1 to 19	0.38	.544	0.26
Verbal memory (domain *z* scores)	**0.05 (0.83)**	**-0.14 to 2.09**	**-0.72 (1.02)**	**-0.17 to 0.47**			
CMS Word Lists							
Learning	8.75 (2.01)	6 to 14	6.86 (3.53)	1 to 10	2.26	.151	0.64
Delayed	10.17 (2.29)	7 to 15	8.29 (1.80)	6 to 11	3.45	.081	0.88

Composite domain/Tests within domain	Mild TBI (*n* = 12) *M(SD)*	Mild TBI (*n* = 12) Range	Moderate-Severe TBI (*n* = 12) *M(SD)*	Moderate-Severe TBI (*n* = 12) Range	*F*	*p*	ESE
Visual memory (domain *z* scores)	**0.23 (0.76)**	**-0.12 to 1.34**	**-0.33 (0.88)**	**-0.09 to 0.67**			
CMS Dot Locations							
Learning	10.58 (3.53)	4 to 14	8.92 (4.46)	1 to 18	1.03	.321	0.40
Total	10.58 (3.20)	6 to 15	8.08 (3.06)	1 to 13	3.82	.063	0.77
Delayed	10.00 (2.52)	7 to 14	8.58 (2.75)	2 to 12	1.73	.202	0.52
RCF 30-min delayed Recall	17.04 (5.89)	8.5 to 29	13.58 (6.57)	2 to 21	1.84	.188	0.54
Working memory (domain *z* scores)	**0.04 (0.64)**	**-0.11 to 1.27**	**-0.58 (1.11)**	**-0.21 to 1.43**			
CMS Numbers							
Backward	7.58 (2.50)	3 to 13	6.50 (3.75)	2 to 13	0.70	.414	0.33
Total	7.33 (2.02)	4 to 10	4.58 (3.15)	1 to 10	6.50	.018*	1.00
Inhibition (domain *z* scores)	**0.16 (0.82)**	**-0.28 to 2.17**	**-0.65 (0.91)**	**-0.30 to 0.68**			
NEPSY-II Inhibition							
Inhibition-Inhibition combined	5.92 (2.91)	4 to 13	4.82 (3.19)	1 to 9	0.75	.397	0.35
Inhibition-Inhibition completion time	9.83 (3.07)	7 to 19	6.00 (2.75)	2 to 10	9.34	.006**	1.27
Cognitive flexibility (domain *z* scores)	**0.21 (0.62)**	**-0.01 to 1.28**	**-0.60 (0.95)**	**-0.48 to 1.42**			
NEPSY-II Design Fluency	7.00 (2.41)	4 to 11	4.00 (2.13)	1 to 8	10.42	.004**	1.28
NEPSY-II Inhibition							
Inhibition-Switching combined	5.83 (2.12)	1 to 10	6.11 (4.31)	1 to 14	0.04	.848	0.08
Inhibition-Switching completion time	10.00 (3.05)	7 to 19	7.22 (2.22)	4 to 11	5.33	.032*	1.01

Note. Data presented are *z* scores (converted *z* scores based on the entire TBI sample, $N = 24$) for composite domain categories and scaled scores (SS) for most individual outcome variables. Scaled scores are presented with the average performance and standard deviation in parentheses of each group's participants. For RCF 30-min Delayed Recall, raw scores are presented. ESE = Cohen's *d* is effect size estimate used in analyses.
*$p < 0.05$. **$p < 0.01$.

Regression results. As was the case with Hypothesis 1, multiple regression was employed as a more powerful analysis and a confirmatory method for the results obtained from the ANOVA analysis.

Primary multiple regression analyses. The same procedure for multiple regression analysis used for testing Hypothesis 1 was employed for Hypothesis 2. As before, all assumptions for regression analysis (normality, linearity, and homoscedasticity) were met for each domain. For each hierarchical regression analysis, group membership was entered at the first step, age was entered at the second step, and sex was entered at the third step.

As shown in Table 14, the only statistically significant overall regression model was that for the domain of selective/focused attention. The beta values (standardized correlation coefficients) derived from these analyses suggested that group membership, specifically, was a statistically significant predictor of neuropsychological performance in this domain, even when age and sex differences were controlled for (i.e., participants in the moderate-severe TBI group demonstrated worse performance than those in the mild TBI group).

Selective/focused attention. As shown in Table 15, the regression analysis on the selective/focused attention data indicated that group membership was a statistically significant predictor of performance, with participants in the control group doing better than those in the TBI group, even when age and sex were controlled for. Furthermore, the analysis showed that neither age nor sex was a significant predictor of performance in this domain.

As Table 15 also shows, group membership alone accounted for 15% of variability in performance in the domain of selective/focused attention. The overall regression model, with group membership, age, and sex included, explained 23% of the variability in selective/focused attention performance, and was a statistically significant fit for the data (see Table 14).

Table 14

Hypothesis 2: Primary regression model for all cognitive domains

	Cognitive domain									
	IQ		Attention			Memory			Executive function	
	Verbal	Performance	Selective/ focused	Sustained	Sustained/ divided	Visual	Verbal	Working	Inhibition	Cognitive flexibility
β: Mild vs. Mod-Severe	-0.310	-0.540	-0.517	-0.496	-0.104	-0.511	-0.581	-0.296	-0.457	-0.612
Model $F(1,44)$	1.079	2.018	3.273	1.533	0.681	2.223	1.497	1.397	2.427	2.805
Model p-level	0.381	0.144	0.043*	0.239	0.574	0.117	0.256	0.273	0.097	0.066
Step 1 R^2	0.089	0.122	0.147	0.114	0.017	0.074	0.109	0.074	0.158	0.179
Step 2 R^2	0.046	0.086	0.258	0.074	0.031	0.091	0.053	0.075	0.193	0.142
Step 2 ΔR^2	< 0.001	0.005	0.138	0.005	0.034	0.055	< 0.001	0.041	0.070	0.002
Step 3 R^2	0.139	0.117	0.299	0.068	0.045	0.138	0.077	0.049	0.163	0.191
Step 3 ΔR^2	0.010	0.067	0.007	0.036	0.035	0.080	0.072	0.018	0.011	0.079

*$p < 0.05$.

Table 15
Hypothesis 2: Regression analysis results for significant selective/focused attention domain

	β	*t*	*p*
Step 1			
Constant		1.539	0.138
Group: Mild vs. Moderate-Severe	-0.430	-2.231	0.036*
Step 2			
Constant		-1.343	0.194
Group: Mild vs. Moderate-Severe	-0.476	-2.628	0.016*
Age	0.374	2.069	0.051
Step 3			
Constant		-0.959	0.349
Group: Mild vs. Moderate-Severe	-0.517	-2.504	0.021*
Age	0.378	2.047	0.054
Sex	-0.091	-0.446	0.661

Note. For Step 1, $R^2 = 0.15$; for Step 2, $R^2 = 0.26$ and $\Delta R^2 = 0.14$; for Step3, $R^2 = 0.23$ and $\Delta R^2 = 0.01$.
*$p < 0.05$.

Post-hoc results for individual outcome measures

Post-hoc multiple regression analyses. The same procedure for post-hoc regression analyses used for testing Hypothesis 1 was used for investigating Hypothesis 2. Again, the *z*-score of each outcome measure was used as the dependent variable, with group membership, age, and sex used as predictor variables.

Selective/focused attention measures. The individual outcome measures comprising this domain were the CMS Numbers Forward subtest and scores from the TEA-Ch Sky Search subtest (targets, time per target, and Sky attention).

As Table 16 shows, the overall models indicated that group membership and age were statistically significant predictors of performance on the CMS Numbers Forward subtest only. Table 17 shows more details of the hierarchical regression models fitted to the data from that subtest. As the table shows, when age and sex were held constant, group membership was statistically significantly associated with performance on Numbers Forward, with participants in the moderate-severe TBI group doing worse than those in the mild TBI group. As Table 17 also shows, when group membership and sex were held constant, age was statistically significantly associated with performance on Numbers Forward. However, unlike group membership, age was associated with a better performance by participants in the moderate-severe TBI group than those in the mild TBI group. Sex was not a statistically significant predictor of performance on this subtest.

Table 16 also shows that group membership alone accounted for approximately 27% of the variability in performance on the Numbers Forward subtest. Group membership together with age accounted for 39% of the variability in test performance. The overall regression model with group

membership, age, and sex included accounted for 37% of variability in performance on the Numbers Forward subtest and was a statistically significant fit for the data (see Table 16).

Finally, a regression equation was constructed for the prediction of group membership by neuropsychological test scores for the CMS Numbers Forward subtest: Group = -1.416 + 0.372(age) + 0.131(sex) - 0.533.

Table 16
Hypothesis 2: Post-hoc regression model results for each outcome measure in the domain of selective/focused attention

			Step 1	Step 2		Step 3	
Outcome Measure	$F(1,20)$	p	R^2	R^2	ΔR^2	R^2	ΔR^2
CMS Numbers Forward[a]	5.504	0.00	0.266	0.385	0.140	0.370	0.014
TEA-Ch Sky Search							
Targets	1.239	0.32	0.045	0.007	0.080	0.030	0.076
Time per Target	2.659	0.07	0.165	0.213	0.080	0.178	0.003
Attention	1.710	0.19	0.132	0.126	0.032	0.085	0.002

[a]Group membership significant in determining performance on this outcome variable.

Table 17
Hypothesis 2: Post-hoc regression analyses results for the CMS Numbers forward subtest

	β	t	p
Step 1			
Constant		2.299	0.031*
Group: Mild vs. Moderate-Severe	-0.546	-3.057	0.006**
Step 2			
Constant		-1.234	0.227
Group: Mild vs. Moderate-Severe	-0.593	-3.596	0.002**
Age	0.378	2.292	0.032*
Step 3			
Constant		-1.416	0.172
Group: Mild vs. Moderate-Severe	-0.533	-2.858	0.010*
Age	0.372	1.231	0.037*
Sex	0.131	0.707	0.488

Note. For Step 1, $R^2 = 0.27$; for Step 2, $R^2 = 0.39$ and $\Delta R^2 = 0.14$; for Step3, $R^2 = 0.37$ and $\Delta R^2 = 0.01$. *$p < 0.05$. *$p < 0.01$.

Conventional between-groups analysis

Most previously published papers comparing mild, moderate, and severe TBI groups to healthy controls employ ANOVA (either factorial or one-way) to assess between-groups differences (see, e.g., Catroppa & Anderson, 2005; Ewing-Cobbs et al., 1998; Nadebaum et al., 2007)). Although the 2-group comparisons above allow for an easily interpretable and powerful regression analyses, for the sake of completeness and comparison with previous studies I now present results of a series of ANOVAs, each using group (mild TBI versus moderate-severe TBI versus control) as

the independent variable and scaled/raw scores for each individual outcome variable as the dependent variable.

ANOVA results. The assumption of normality was upheld for all of the datasets. However, Levene's test of homogeneity was violated for the CMS Numbers Backward and NEPSY-II Inhibition-Switching combined outcome variables (see Table 18). In this instance, the non-parametric Kruskal-Wallis ANOVA test was used to assess for significant between-group differences.

Bonferroni's adjusted *p*-level was employed, where $p = .05$ is divided by the number of comparisons (Howell, 1999). In this case, $p = .05/23 = .0021$ was used as the significance level. Table 19 shows the results of all between-group comparisons. The series of ANOVAs showed that there were statistically significant between-group differences on the following measures at the unadjusted alpha level ($p < .05$): WASI Vocabulary, WASI Similarities, CMS Numbers Forward and Numbers Total, and NEPSY-II Design Fluency and Inhibition-Inhibition completion time. At the adjusted alpha level ($p < .0021$), the between-group differences remained statistically significant on the following measures: WASI Similarities, CMS Numbers Forward, and NEPSY-II Design Fluency. Effect size estimates suggested that the magnitude of difference for each of these was in the range conventionally described as small.

Post-hoc Tukey's HSD was used to assess exactly where the significant differences were on all of the measures where statistical significance was found at the .05 level. Significant differences were found between the moderate-severe TBI and control groups on WASI Vocabulary ($p = 0.004$), WASI Similarities ($p = 0.0005$), CMS Numbers Forward ($p = 0.002$), and CMS Numbers Total ($p = 0.006$). On the NEPSY-II Inhibition-Inhibition completion time measure, significant differences were found between the moderate-severe TBI and mild TBI groups, $p = 0.006$, and the moderate-severe TBI children and healthy controls, $p = 0.013$. Finally, on NEPSY-II Design Fluency outcome measure, significant differences were found between the moderate-severe TBI and mild TBI groups, $p = 0.014$, as well as between the moderate-severe TBI group and the controls, $p = 0.002$. Of particular interest here is that there were no statistically significant differences between the mild TBI and the control groups on any of the outcome measures.

Based on this analysis and these results, the areas of cognitive functioning most affected in children with moderate-severe TBI are verbal abilities including semantic knowledge and abstract semantic reasoning, attention and concentration abilities, the ability to inhibit automatic responses, and the ability to use flexible thought processes.

Table 18
Conventional 3-Group Analysis: Levene's test results

Test and domain	Levene's *F*	Levene's *p*
WASI: Verbal IQ		
Vocabulary	1.183	0.316
Similarities	0.866	0.428
WASI: Performance IQ		
Block Design	3.117	0.054
Matrix Reasoning	0.288	0.751
TEA-Ch Sky Search: Selective attention		
Targets	1.386	0.261
Time per target	0.098	0.907
Attention	0.342	0.712
TEA-Ch Score!: Sustained attention	0.030	0.971
TEA-Ch Sky Search DT: Sustained/divided attention	2.524	0.092
CMS Dot Locations: Visual memory		
Learning	0.714	0.841
Total	0.575	0.567
Delayed Recall	0.155	0.857
RCF 30-min delayed recall: Visual memory	0.431	0.653
CMS Word Lists: Verbal memory		
Learning	2.093	0.137
Delayed recall	1.217	0.307
Delayed recognition	2.749	0.077
CMS Numbers: Working memory		
Forward	0.130	0.878
Backward	4.140	0.022*
Total	1.284	0.287
NEPSY-II: Executive functioning		
Design Fluency	0.493	0.614
Inhibition-Naming combined	0.914	0.408
Inhibition-Naming completion time	0.638	0.533
Inhibition-Inhibition combined	0.259	0.773
Inhibition-Inhibition completion time	0.091	0.913
Inhibition-Switching combined	5.650	0.007**
Inhibition-Switching completion time	0.612	0.547

*$p < 0.05$, **$p < 0.01$.

Table 19
Conventional 3-Group Analysis: ANOVA results

Composite domain/Tests within domain	*df*	*F*	*p*	ESE
Verbal IQ				
WASI				
Vocabulary	2, 45	5.90	.005*	0.17
Similarities	2, 45	9.40	< .001***	0.26
Performance IQ				
WASI				
Block Design	2, 45	2.94	.063	0.08
Matrix Reasoning	2, 45	1.52	.231	0.02
Selective/focused attention				
CMS Numbers Forward	2, 45	7.31	.002**	0.21
TEA-Ch Sky Search				
Targets	2, 44	1.23	.302	0.01
Time per target	2, 44	3.24	.050	0.09
Attention	2, 44	2.59	.087	0.06
Sustained attention				
TEA-Ch Score!	2, 43	1.32	.277	0.01
Sustained/divided attention				
TEA-Ch Sky Search DT	2, 43	0.97	.388	<0.01
Verbal memory				
CMS Word Lists				
Learning	2, 40	2.61	.086	0.07
Delayed	2, 40	2.23	.121	0.06
Visual memory				
CMS Dot Locations				
Learning	2, 45	0.63	.536	0.02
Total	2, 45	2.43	.100	0.06
Delayed	2, 45	1.87	.167	0.04
RCF 30-min delayed recall	2, 45	1.47	.240	0.02
Working memory				
CMS Numbers				
Backward	2, 45	1.67	.120	0.03
Total	2, 45	5.49	.007**	0.16
Inhibition				
NEPSY-II Inhibition				
Inhibition-Inhibition combined	2, 43	1.88	.166	0.04
Inhibition-Inhibition completion time	2, 43	6.15	.004**	0.19
Cognitive flexibility				
NEPSY-II Design Fluency	2, 45	7.10	.002**	0.21
NEPSY-II Inhibition				
Inhibition-Switching combined	2, 42	0.13	.882	0.04
Inhibition-Switching completion time	2, 42	2.80	.072	0.08

Note. ESE = effect size estimate; in this case, adjusted R^2.
*$p < .05$. **$p < .01$. *** $p < .001$.

Discussion

The primary aim of this study was to explore, in the South African context, the effects of TBI on children's neuropsychological functioning and to investigate whether the presence of a TBI allows for predictions about functioning within a specific cognitive domain. Stated otherwise, this research attempted to answer the question of whether, in a low-SES South African population, a TBI sustained in childhood leads to persistent neuropsychological sequelae for months (or even years) after insult.

Furthermore, this study was aimed at generating an updated profile of neuropsychological functioning following TBI in a South African pediatric population. The generation of an updated profile of outcomes will, in due course, inform comprehensive and effective neuropsychological rehabilitation programs, and will allow the development of school programs with realistic expectations, both geared towards facilitating the child's adaptive functioning in his/her environment (Baxter, Cohen, & Ylvisaker, 1995; Tranel & Eslinger, 2000).

Ultimately, this endeavor will serve as an initial step in generating a battery of neuropsychological tests suitable for testing South African children with TBI. Essentially, such a test battery will be sensitive to the specific South African cultural context with utility in both clinical and research practice. A major criticism of neuropsychological testing has been the applicability of tests developed in Western countries in culturally divergent settings (Cohen & Malcolm, 2005; Nell, 2000, 2001). The socio-economic and cultural contexts of these Western countries are very different to developing-world countries like South Africa which are culturally divergent and relatively resource poor. This situation clearly indicates the need for the development of culturally appropriate norms that will make test performance on measures normed in Western populations more reliable.

This Discussion section will be organized as follows: First, I will review the results, examining the relative performance of participants in the three groups (mild TBI, moderate-severe TBI, and controls) on the battery of neuropsychological tests. As a reminder, the set of hypotheses tested by the statistical analyses reported in the Results section were that children with TBI would, in general, perform significantly more poorly measures of cognitive functioning than age-, sex-, and SES-matched healthy controls, and that participants with moderate-severe TBI would perform significantly more poorly on those measures than age-, sex, and SES-matched children with mild TBI. This discussion of test results will centre largely around questions of how South African children with TBI compare to their international counterparts. This aim will be accomplished by evaluating similarities and discrepancies between the current data and those from previously published studies.

After reviewing, summarizing, and discussing the data, I will proceed to discuss the possible reasons for inconsistent results and limitations and directions for future research.

Review and Summary of Results

The results from both ANOVA and regression analyses provided only partial confirmation of the hypotheses: participants with TBI performed more poorly on measures of general intellectual functioning and executive functioning than control participants, and children with moderate-severe TBI performed more poorly than those with mild TBI on a measure of selective/focused attention.

VIQ and PIQ. Analyses revealed that, overall, TBI participants performed more poorly on the WASI Verbal IQ subtests (Vocabulary and Similarities). More specifically, the overall regression model showed group membership to be a significant predictor of outcome on both subtests taken separately, even when age and sex of the participant were controlled for. A 3-group ANOVA (mild versus moderate-severe versus control group) showed the poor performance by the TBI group to be associated with the moderate-severe TBI group with post-hoc Tukey's analysis indicating the significant difference to lie between the moderate-severe TBI and control groups for both WASI Vocabulary and Similarities.

There were no statistically significant between-group differences when comparing mild to moderate-severe TBI participants, however, even though examination of the means showed that those in the mild TBI group performed consistently better than those in the moderate-severe group on all measures within these domains. Effect size estimates were shown to be in the medium range for the mild versus moderate-severe TBI groups on measures of Verbal IQ, indicating that given a larger sample, there is a relatively strong possibility that a significant difference will be found in the general population.

These latter results are not consistent with those from previously published studies. A consistent trend in the literature has been that children with more severe injuries perform worse on measures of PIQ than those with mild TBI (see, e.g., Anderson et al., 2004), and that VIQ returns to normal levels in children with severe TBI by 1 year post-injury (Catroppa & Anderson, 2003).

As one of the aims of the present study was to lay the groundwork of establishing a battery of measures that can be used to distinguish children with TBI from those without, it is important to note that the results from the post-hoc regression analysis indicate that the Vocabulary and Similarities subtests would provide the most reliable prediction. This indicates that these tests are reliable measures of verbal abilities in a South African population.

With regard to the comparison between the overall TBI group and healthy controls, the between-group analysis with regard to PIQ was found to be statistically non-significant. Looking at the means and standard deviations, the TBI group surprisingly performed better than the controls on

the WASI Block Design subtest though performance on WASI Matrix Reasoning subtest was poorer for the TBI participants. The average scores show both groups to perform within the average range which could be an indication that the WASI Block Design and WASI Matrix Reasoning subtests are relatively insensitive to brain injury in this population. Effect size estimates were in the small range for the TBI versus control group comparison on measures of PIQ suggesting very little likelihood of finding any effect in the larger population even after increasing the sample size.

Comparison of the mild versus moderate-severe TBI groups also showed PIQ to be statistically non-significant. Means and standard deviations showed the mild TBI participants to perform better than moderate-severe TBI participants on both measures of PIQ. Effect size estimates were in the medium range for the comparison of these injury groups on measures of PIQ. This means that given a larger sample size, there is a likelihood that an effect will be found in the wider population.

The data suggest that crystallized knowledge based on a fund of semantic knowledge, more than fluid reasoning, is impaired in South African children with moderate-severe TBI relative to demographically matched healthy counterparts. More specifically, the TBI participants demonstrated impairment in expressive vocabulary and verbal knowledge, as well as verbal concept formation and abstract verbal reasoning abilities. As with the mild versus moderate-severe TBI comparison, however, these results are not consistent with those from previous literature. Overall, many previous studies, of both South African and other populations, report that PIQ is most affected, while VIQ returns to normal levels of functioning, following a childhood TBI (see, e.g., Anderson et al., 1998; Catroppa & Anderson, 2003; Hemp, 1989). However, the current findings were similar to those reported by Anderson and colleagues (1998), who showed that, when compared to healthy controls, moderate-to-severe TBI was associated with significant impairment in VIQ while differences in PIQ scores were not statistically significant. It could be that the TBI children in the current study as in Anderson and colleagues' research had poor verbal abilities, even before the injury, than the children in the studies where these functions have been found to be relatively unaffected. In the current sample, this could be attributed to test administration not being in these children's home language, a factor which will be discussed later.

Selective/focused attention. Analyses revealed significant differences in the domain of selective/focused attention when comparing the TBI and control groups. This difference was associated with a poorer performance by the TBI group on the CMS Numbers Forward when compared to controls. The 3-group ANOVA analysis confirmed the significant difference found between the TBI versus control group comparison. Post-hoc Tukey's found the significant difference to lie between the moderate-severe TBI and control groups with a poorer performance associated with participants in the moderate-severe TBI group.

The overall regression model showed group membership to be a significant predictor of outcome when age and sex of the participant were controlled for. Results from the post-hoc regression analysis indicate that the Numbers Forward subtest would provide the most reliable prediction of group membership. Again, this indicates that CMS Numbers Forward is a reliable measure of functioning within the domain of selective/focused attention in the South African pediatric population.

Post-hoc regression analyses also revealed age to be significantly associated with a poorer performance by the TBI participants on the TEA-Ch Sky Search Targets subtest. These results would indicate the important influence that age at injury has on neuropsychological outcome, a factor that requires further investigation within the current TBI sample. The data suggests that South African children with moderate-severe TBI experience difficulty in attention and concentration compared to healthy uninjured children. More specifically, children who have sustained a moderate-severe TBI have impaired ability to focus on one stimulus while filtering out distractors.

The current results are consistent with the findings by Catale and colleagues (2009) where children with TBI demonstrated difficulty on tasks of selective/focused attention compared to healthy, uninjured children. However, the majority of previous research points to TBI being associated with impairment in all attentional systems (see, e.g., Anderson et al., 2001; Fenwick & Anderson, 1999; Lowther & Mayfield, 2004; Yeates et al., 2002). Anderson and colleagues (1998) produced contrasting results when they found that children who had sustained a TBI demonstrated impairment in the ability to sustain and divide attention while selective/focused attention was relatively spared.

The studies by Catale and colleagues (2009) focused only on selective/focused attentional abilities while Anderson and colleagues (1998) only assessed the ability to sustain/divide and select/focus attention. Stated otherwise, these studies did not include all attentional systems which is why comparison cannot be made between these studies and the current research so as to evaluate why only selective/focused attention has been found to be affected. Possible reasons for the current finding with regards to testing conditions will be discussed at a later stage.

With regard to mild versus moderate-severe TBI group comparisons, analyses revealed significant differences in the domain of selective/focused attention. ANOVA analyses showed children with moderate-severe TBI to perform more poorly than those with mild TBI on the CMS Numbers Forward and TEA-Ch Sky Search Time per Target subtest. The 2-group ANOVA results for CMS Numbers Forward were confirmed by the 3-group comparison for this measure which showed the moderate-severe TBI participants to perform significantly worse than the mild TBI participants.

Multiple regression analyses confirmed only the significant ANOVA results for CMS Numbers Forward. The overall regression model showed injury severity to be a significant predictor of outcome when age and sex of the participant were controlled for. The results from the post-hoc regression analysis indicate that the CMS Numbers Forward subtest would provide the most reliable prediction. This is in line with regression results of the TBI versus control group comparison that CMS Numbers Forward will be a reliable measure in the test battery for identifying TBI in South African children.

The overall regression model also indicated age at the time of injury to be a significant predictor of neuropsychological outcome on CMS Numbers Forward. However, age was associated with an increased performance by the moderate-severe group. The mild TBI participants tended to be younger at the time of injury than the moderate-severe TBI participants (though this difference was shown to be statistically non-significant), a factor which has been shown to be associated with poorer outcome following pTBI (see, e.g., Anderson & Moore, 1995; Semple et al., 1998; Verger et al., 2000). This could explain the poorer performance on CMS Numbers Forward by the mild TBI participants compared to children in the moderate-severe group.

The current results are consistent with the bulk of the findings showing that children with moderate-severe injuries performed more poorly in the domain of selective/focused attention than children with mild TBI (see, e.g., Kersel et al., 2001; Wassenberg et al., 2004; Willmott et al., 2000). In contrast Catale and colleagues (2009) showed even children with mild TBI experienced difficulty on tasks of selective/focused attention compared to healthy, uninjured children. While age was shown to be factor in the poorer performance of the mild TBI compared to the moderate-severe TBI group, the reason given for this poor performance in the Catale and colleagues study was that attention is very sensitive to the effects of TBI which is why even children with mild injuries will demonstrate residual deficits.

Sustained attention. No significant differences were found in the domain of sustained attention in the TBI versus control group comparison. When considering the average scores for each group, the children with TBI seem to perform at a similar level to controls. The effect size estimate was shown to be in the small range which points to the fact that this trend in performance will more likely not be found in the general population after increasing the sample size. These results are inconsistent with previous literature findings where the ability to sustain attention has been found to be significantly affected by pTBI (see, e.g., Catroppa & Anderson, 2003).

As with the comparison of TBI versus control group participants, differences between the mild and moderate-severe TBI participants were found to be statistically non-significant. However, average scores showed the moderate-severe TBI group to perform more poorly in the sustained attention domain than the mild TBI group. The effect size estimate was in the medium range

indicating a relatively strong possibility of finding an effect in the general population. These results are not consistent with previous findings where children with more severe injuries showed more severe sustained attentional impairments than those with mild injuries (see, e.g., Catroppa & Anderson, 2003, 2005; Ewing-Cobbs et al., 1998).

Sustained/divided attention. When comparing the TBI participants to those in the control group, results were not found to be statistically significant. Descriptive statistics indicate that the TBI participants performed more poorly than controls on the measure of sustained/divided attention. The effect size estimate was in the small range which suggests that finding any effect in the general population after increasing the sample size is not very likely. The statistically non-significant results are inconsistent with previous findings where the ability to sustain and divide attention has been found to be impaired in children with moderate-severe TBI (see, e.g., Anderson et al., 1998).

Analyses did not reveal any statistically significant results for sustained/divided attention when mild TBI participants were compared to those in the moderate-severe TBI group. However, descriptive statistics did, in fact, indicate that the moderate-severe TBI group performed more poorly than the mild TBI group on the measure of sustained/divided attention. The effect size for this domain was in the small range indicating a small probability of finding any effect in the wider population after increasing the sample size. The statistically non-significant results are not consistent with previous findings where children with moderate-severe TBI tend to perform worse on measures of attentional abilities than children with milder injuries (Ewing-Cobbs et al., 1998; Kersel et al., 2001; Yeates et al., 2005).

Verbal memory. Statistical analyses did not indicate significant differences between the TBI and control participants in the verbal memory domain. However, examination of averages shows the TBI group to perform worse than the controls on all measures of verbal memory. Effect size estimates for the measures in this domain were in the medium range. This suggests a relatively strong possibility of seeing this effect in the general pediatric population. The non-significant results in the present study are inconsistent with previous literature findings where children with TBI demonstrated impairments in verbal learning and recall (see, e.g., Anderson et al., 2001; Hemp, 1989; Yeates et al., 2002).

As with the comparison of the TBI versus control group, no significant differences were found between the mild and moderate-severe TBI participants in the domain of verbal memory. However, average scores show the moderate-severe TBI group to perform worse than the mild TBI group on all measures of verbal memory. Effect size estimates were shown to be in the medium range for CMS Word Lists learning and large for CMS Word Lists delayed. These estimates indicate a strong likelihood of finding this effect in the wider population given a larger sample. The

non-significant results in the present study are not consistent with previous literature findings where severely injured children demonstrate slower and less complete recovery of memory functions than children with mild TBI (see, e.g., Anderson et al., 2000; Catroppa & Anderson, 2003, 2005).

Visual memory. Comparison of the TBI versus control groups did not reveal any statistically significant results in the domain of visual memory. However, average scores show the TBI participants to perform consistently worse than controls on all measures of visual memory. Effect size estimates were small for CMS Dot Locations learning and in the medium range for CMS Dot Locations total and delayed recall. These estimates indicate that finding a significant effect in the wider population with CMS Dot Locations learning after the sample has been increased is not very likely while there is more of a likelihood of finding an effect with CMS Dot Locations total and delayed recall. The current results are inconsistent with previous research where TBI was associated with decreased performance on tests of visual memory (see, e.g., Lowther & Mayfield, 2004).

With regards to the mild versus moderate-severe TBI group comparison, no statistically significant results were found although average scores show the moderate-severe TBI participants to perform consistently worse than mild TBI participants in the domain of visual memory. For CMS Dot Locations learning the effect size estimate was small while those for CMS Dot Locations total and delayed recall were in the medium range. The estimate for CMS Dot Locations learning suggests that a significant effect in the general population after increasing the sample is unlikely. The estimates for CMS Dot Locations total and delayed recall, on the other hand, indicate a relatively good probability of finding this effect in the wider population after an increase in sample size. Again, the results from the present study are inconsistent with previous research findings where severely injured children performed worse than children with mild TBI on tests of visual memory (Yeates et al., 2002; Hemp, 1989).

Working memory. Comparison of the participants in the TBI group versus those in the control group delivered significant ANOVA results for CMS Numbers total. The data showed the TBI children to perform more poorly on this measure when compared to their demographically matched healthy counterparts. However, this poor performance was attributed to an attention problem as seen from the result for CMS Numbers Forward rather than a working memory deficit. CMS Numbers Backward was found to be statistically non-significant which confirms that the significant result found for CMS Numbers total could not be attributed to impaired working memory.

A 3-group comparison showed the poor performance by the TBI group on the CMS Numbers Total measure to be associated with the moderate-severe TBI participants at the unadjusted significance level ($p < .05$). At the adjusted significance level ($p < .0021$) the results

were found to be statistically non-significant. Post-hoc Tukey's showed the significant difference at $p < .05$ to lie between the moderate-severe TBI and control groups. The significant results from the ANOVA analyses were not confirmed by multiple regression analyses. The current findings do not support previous research where working memory has been found to be impaired in children with TBI (see, e.g., Levin et al., 2004; Mongeot et al., 2002).

With regards to comparing mild to moderate-severe TBI participants, no significant results were found in working memory abilities. Again, averages show the moderate-severe TBI children to perform more poorly on measures of working memory than children with mild TBI. Effect size estimates were small for CMS Numbers Backward and large for CMS Numbers Total. These estimates were in the small range for CMS Numbers Backward and large for CMS Numbers Total. These estimates indicate a small probability of finding a significant effect in the wider population with CMS Numbers Backward while CMS Numbers Total is associated with a very high likelihood of finding an effect in the general population with an increase in sample size. The current findings do not support previous research where severe TBI children performed significantly more poorly on working memory tasks than did those with mild injuries (see, e.g., Levin et al., 2004).

Inhibition. Comparing TBI participants to those in the control group did not reveal any statistically significant results. However, average scaled scores indicate a poorer performance on all inhibition measures by the TBI participants when compared to controls. The effect size estimate for NEPSY-II Inhibition-Inhibition combined was in the medium range while the effect size estimate for NEPSY-II Inhibition-Inhibition completion time was in the small range. These estimates suggest that the likelihood of finding a significant effect in the wider pediatric population for the NEPSY-II Inhibition-Inhibition combined measure is relatively likely with an increased sample size while finding an effect for the NEPSY-II Inhibition-Inhibition completion time measure is not very likely.

In contrast, the 3-group comparison found the moderate-severe TBI group to be significantly associated with a poorer performance at the unadjusted significance level ($p < .05$) on the NEPSY-II Inhibition-Inhibition completion time measure compared to control participants. At the adjusted significance level ($p < .0021$) these results did not reach statistical significance.

The results from the 3-group comparison are consistent with established literature where impairments have been found in behavioural control and the ability to inhibit automatic responses in children with TBI (see, e.g., Ewing-Cobbs et al., 2004; Hanten et al., 200, 2002; Levin et al., 2001; Mongeot et al., 2002).

With regards to the mild versus moderate-severe TBI group comparison, results from the ANOVA analyses indicated a poorer performance by the moderate-severe TBI participants on the NEPSY-II Inhibition-Inhibition Completion Time measure than mild TBI participants. The results for the NEPSY-II Inhibition Completion Time measure was confirmed by the 3-group ANOVA

when the moderate-severe TBI participants were shown to perform significantly worse than mild TBI participants. Results from the ANOVA analyses showed South African children with moderate-severe TBI to have an impulsive response style with poor inhibitory control when compared to those with mild TBI. However, regression analyses did not confirm the statistically significant results found by the ANOVA analyses. The current results from the ANOVA analyses are consistent with previous findings where more severe injuries are associated with more severe inhibitory control impairments than less severe injuries (see, e.g., Mandalis et al., 2007; Muscara et al., 2008

Cognitive flexibility. ANOVA results for the comparison of the TBI versus control group showed the participants with moderate-severe TBI to perform worse on the NEPSY-II Design Fluency measure than control participants. A 3-group ANOVA confirmed these results and found the moderate-severe TBI group to demonstrate a significantly poorer performance on the NEPSY-II Design Fluency measure than controls. Multiple regression analyses did not confirm the results from the ANOVA analyses. These findings from the ANOVA analyses are consistent with previous studies that have found TBI participants to experience difficulty in the ability to use flexible cognitive processes (Slomine et al., 2002).

With regards to comparing mild TBI to moderate-severe TBI participants, ANOVA analyses revealed significant differences in the domain of cognitive flexibility. More specifically, this difference was associated with a poorer performance by the moderate-severe participants on the NEPSY-II Design Fluency and NEPSY-II Inhibition-Switching measures when compared to children with mild TBI. Again, the results for NEPSY-II Design Fluency were verified by the 3-group comparison. The children in the moderate-severe TBI group performed significantly worse than those in the mild TBI group on NEPSY-II Design Fluency. These findings were not verified by multiple regression analyses.

Data from the ANOVA analyses indicate that South African children with TBI, more specifically those with moderate-severe injuries, experience difficulty in the ability to produce novel and unique designs through the use of flexible thought processes. Regression analyses did not confirm the ANOVA results and showed injury severity not to be a significant predictor of outcome. The current ANOVA results are consistent with established literature findings where children with more severe injuries perform worse on tasks requiring cognitive flexibility than children with milder injuries (see, e.g., Nadebaum et al., 2007; Roncandin et al., 2004; Wozniak et al., 2007).

Possible Reasons for Inconsistent Results

Sample size. The first and perhaps most obvious possible reason for the lack of significant results is the relatively small sample used in the present research. As is evident for many of the domains, average scores indicate the TBI group to perform consistently worse than healthy controls. Similarly, the participants with moderate-severe TBI generally performed worse on measures of neuropsychological functioning than those with mild TBI. Effect size estimates were shown to be in the large range for two measures (for example, CMS Word Lists delayed recall and CMS Numbers total measures) while effect size estimates for the majority of test measures were within the medium range. This would indicate that given a bigger sample size, more significant results will be found in this South African population.

Testing conditions. For a number of children with mild injuries testing occurred at their homes as the parents were unable to travel to designated RXH or UCT testing venues due to financial constraints or long distances. Even though traveling expenses were reimbursed, this only happened at the end of the testing session which was problematic for those parents who did not have money to get to the venue. Unlike the designated venues, the children's home environments were often not conducive to administering the test battery. Optimal performance on these tests requires optimal attention and concentration. However, in all of the homes there was constant interference due to many family members sharing the same home. Often the homes had only two or three rooms or as many as three families lived in shacks on the same property which led to testing occurring in very cramped spaces. The present data indicate impairment in attention and concentration of children with TBI. This impairment could, in addition to the TBI, be compounded by the poor testing conditions. These factors could be directly attributed to the low-SES background of these families who live under greatly disadvantaged positions in terms of access to property and resources.

Limitations and Directions for Future Research

The present study had a number of limitations which should all be addressed by future research. The first limitation is that of a small sample size. Many of the trends in the data suggest that a larger sample size would have produced more statistically significant results. Generally, effects size estimates have been shown to be in the medium range. Large effect size estimates were found for Future research should use larger sample sizes which would allow researchers to assess whether test performance patterns are due to chance or to actual differences in the general population.

A second potential limitation is the fact that participants were tested in English which was not a first language for many of the children in the current sample, a factor which could have put these participants at a distinct disadvantage. In clinical practice children often get tested in a

language different from their home language (Cohen & Malcolm). This situation arises from the fact that many commonly-used neuropsychological measures were developed in English-speaking countries like the US and United Kingdom. Studies have found that testees who do not have English as a home language but who are assessed in English perform worse on tests of verbal abilities than their English counterparts (see, e.g., Carstairs, Myors, Shores, & Fogarty, 2006). The poor performance of TBI participants on tests of verbal abilities could be due to the fact that many of these children did not have English as a first language. Future studies should undertake the task of not only translating these tests and making test items more culturally applicable, but also attempt to establish South African developed norms that, though costly, will ensure reliable norms for assessing neuropsychological performance within a South African pediatric population

A third and final limitation is that the present research did not assess the effects of time since injury, premorbid functioning and psychosocial factors, all of which have been shown to be significant predictors of outcome. Furthermore, though age at injury was entered as a factor in the regression analyses, the age band (7 to 10 years old) used in this study was limited so as to minimize the effects of age on neuropsychological test performance. Even after controlling for age at injury in the present sample, the results obtained for CMS Numbers Forward in the selective/focused attention domain still indicate age at injury to be a significant predictor of outcome following pTBI. Future studies should stratify larger samples across these factors so as to investigate their influence on neuropsychological outcome.

Summary and Conclusion

The data presented in the present study indicate that TBI leads to residual neuropsychological impairments years after the injury has occurred. Furthermore, in at least one cognitive domain (selective/focused attention), injury severity is an important predictor of outcome following a pTBI. Children with TBI appear to experience most difficulty in the domains of verbal IQ and selective/focused attention when compared to healthy controls. More specifically, the TBI participants demonstrate impairment in verbal knowledge and abstract semantic reasoning and deficits in the ability to attend to the information at hand. When compared to mild TBI participants, the children with moderate-severe TBI show impairment in attention and concentration abilities, the use of flexible thought processes, and inhibitory control.

The data indicates that with some improvements and adjustments, the neuropsychological measures employed by the present study is a good starting point for developing a culturally sensitive battery for the identification of TBI in South African children. Generally, the effect sizes associated with the measures in this battery fall within the medium range with some falling in the large range. These estimates indicate that significant effects may be found with a larger sample size. In addition, WASI

Vocabulary and Similarities and CMS Numbers Forward have been shown to be reliable measures in separating children with TBI from uninjured children which, therefore, make them a meaningful contribution to a neuropsychological battery for the identification of TBI in South African children

The measures included in the battery are all established neuropsychological tests that have been developed by leading figures in the field of pediatric neuropsychology. On a qualitative basis, test administration was uncomplicated and test instructions were easily understood by both the examiners and the testees. However, the TEA-Ch Creature Counting subtest proved to be too demanding for some participants, particularly those with more severe injuries. Many of these children were unable to meet the rule of counting backward from 15 to 1, in which case the test had to be discontinued. An alternative measure for the assessment of the ability to shift attention will have to be explored.

Finally, on the verbal tasks like WASI Vocabulary and Similarities some of the items were not within the everyday verbal repertoire of South African children. For example, an item like "shovel" was not readily understood by the children in the current sample. The translation of some of the items into culturally appropriate items is needed and is a major undertaking beyond the scope of the current study. This, however, should serve as the groundwork for developing South African normative data which will address issues like construct validity and ultimately generate more statistically reliable data. The point must be made that this battery is not the final product and that continuous research is needed to update and improve the neuropsychological test battery as it stands at this moment.

The data in the current study suggests that many domains of cognitive functioning have been spared in these South African TBI children. There were, for instance, no statistically significant between-group differences in the domains of Performance IQ, sustained attention, sustained/divided attention, verbal memory, and visual memory. Furthermore, no significant differences were found between the mild TBI and control groups on any of the cognitive domains. Cognitive functioning only in the domains of attention and executive functions appear to be significantly affected in this South African pediatric sample. The domain of memory seems to be spared even in the moderate-severe TBI group. In conclusion, the large number of cognitive domains that have been found to be relatively intact in the current sample will create favourable conditions for the development of effective neuropsychological rehabilitation programs, resulting in good functional outcome within the South African pediatric TBI population.

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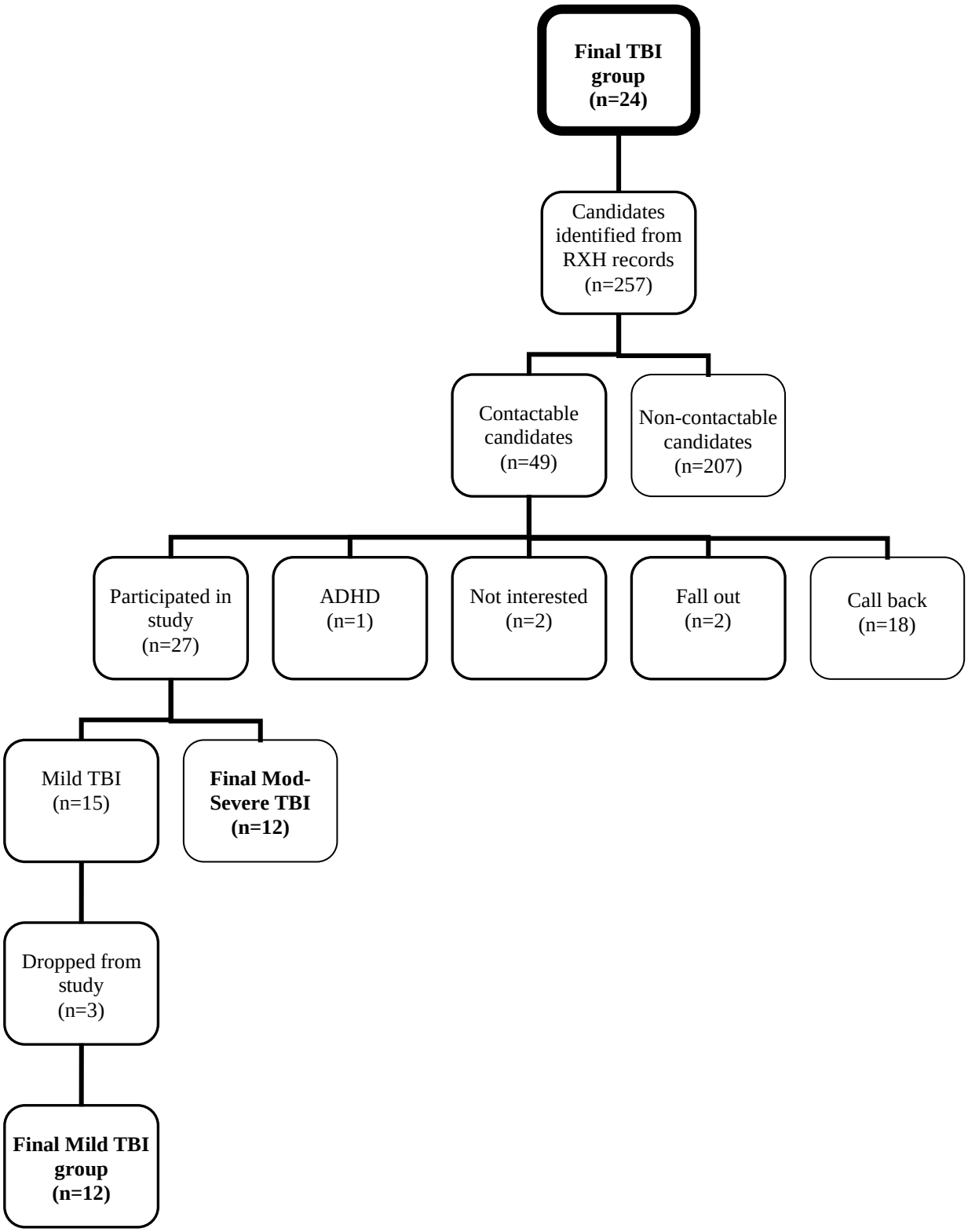
Appendix A
Recruitment Process



Appendix B
Informed Consent Form – Adults

University of Cape Town

Department of Psychology

Informed Consent Form - Adults

A Cognitive Profile of South African children with Traumatic Brain Injury

1. **Invitation and Purpose**

You are invited to take part in a research study about traumatic brain injury in children. We are researchers from the Department of Psychology at the University of Cape Town.

2. **Procedures**

If you decide to take part in this study, we will ask your child to do some puzzles and paper-and-pencil tasks. The assessment will take place over two sessions with duration of about 90 minutes each.

3. **Risks, Discomforts & Inconveniences**

This study does not pose more than low risk to you. The main risk is that your child may become tired or experience some discomfort because of the length of the assessment. This risk will be minimized by allowing your child to stop or take a break whenever s/he so chooses. The other risk is that someone other than the researchers might see your private information, but this risk is still very small because of the safety measures we will take to keep your information safe.

4. **Benefits**

This study is not designed to benefit you. The knowledge we will gain from it, however, will be used to help other families with children who have had a head injury.

5. **Alternatives (Other Options)**

You do not have to participate in this study—it is up to you.

6. **Privacy and Confidentiality**

We will take strict precautions to safeguard your personal information throughout the study. Your information will be kept without your name or other personal identifiers, only a code, in a locked file cabinet.

Study data will be kept on a password-protected, secure server in the Department of Psychology at the University of Cape Town. Only the researchers will be able to access your personal information.

We will conduct the interviews in a private room at Red Cross Hospital or in the Department of Psychology at the University of Cape Town.

7. **Money Matters**

You will receive R100 to help cover the costs of transportation.

8. **Questions**

If you have questions, concerns, or complaints about the study, please contact Nancy Malgas at 073 025 5125, mlgnan001@uct.ac.za, or Dr. Kevin Thomas at 021 650 4608.

9. **Use of Samples/Date for Future Research**

With your permission, we would like to store the data from your child's assessment for use in future research. This is your choice entirely and you are free to say no and still be able to take part in the study. Please check the boxes that apply to your choice:

I do not want my information to be used for any future research. ___

You may use my information for any future research about head injury. ___

I would like to participate in any future research. ____

10. **Signatures**

{Participant's name}_____ has been informed of the nature and purpose of the procedures described above including any risks involved in its performance. He or she has been given time to ask any questions and these questions have been answered to the best of the investigator's ability. A signed copy of this consent form will be made available to the participant.

_____ _____

Investigator's Signature Date

I have been informed about this research study and understand its purpose, possible benefits, risks, and discomforts. I agree to take part in this research as a subject. I know that I am free to withdraw this consent and quit this project at any time, and that doing so will not cause me any penalty or loss of benefits that I would otherwise be entitled to enjoy.

_____ _____

Participant's Signature Date

Appendix C
Assent Form – Children

UNIVERSITY OF CAPE TOWN **RESEARCH ASSENT FORM**

Use Plate or Print:

MRN#:

DOB:

Pt Name:

Protocol Title: A Cognitive Profile of South African Children with Traumatic Brain Injury

Gender:

We want to tell you about a research study we are doing. A research study is a way to learn more about something. We would like to find out more about children who have hurt their heads. You are being asked to join the study because you have had an accident in which your head was hurt.

If you agree to join this study, you will be asked to do some puzzles and paper-and-pencil tasks. We will ask you to come back for a second time. Each visit will be about 90 minutes long

You might become tired or hungry. Remember, you can stop or take a break at any time..

We may learn something that will help other children with a head injury some day.

You do not have to join this study. It is up to you. You can say okay now and change your mind later. All you have to do is tell us you want to stop. No one will be mad at you if you don't want to be in the study or if you join the study and change your mind later and stop.

Before you say **yes or no** to being in this study, we will answer any questions you have. If you join the study, you can ask questions at any time. Just tell the researcher that you have a question.

If you have any questions about this study please feel free to contact **Nancy Malgas** at **073 025 5125** or **Kevin Thomas** at **021 650 4608**.

If you sign your name below, it means that you agree to take part in this research study.

☒ _____ _____

Date (MM/DD/YEAR) **Signature of Child/Adolescent Participant**

Appendix D
Developmental Questionnaire

PAEDIATRIC NEUROPSYCHOLOGY REHABILITATION SERVICE

BACKGROUND INFORMATION QUESTIONNAIRE

All information provided is treated confidentially.

There will be ample time at the assessment to discuss any of the responses further if you would like.

Child's Name: _____

Date of Birth: _____

PREGNANCY AND BIRTH

What complications, if any, were there during the pregnancy?

_____

_____

What medicines (prescribed or non-prescribed) were taken during pregnancy?

_____

_____

If the birth was earlier or later than the expected date, please specify.

_____

What complications, if any, were there during the birth?

_____

_____

Were there any difficulties with bonding?

_____

_____

What was your baby's weight? _____

What complications, if any, were there in the newborn period?

_____

_____

What feeding difficulties, if any, were there?

_____

_____

What sleeping difficulties, if any, were there?

_____

_____

DEVELOPMENT

At what age did your child:

sit unaided? _____
crawl? _____
walk unassisted? _____
dress and undress unassisted? _____
button own clothes? _____
tie shoe laces? _____
say their first word? _____
use 2 words together? _____
write own name? _____

Were there any problems with motor, speech or co-ordination development?

_____

_____

At what age was your child dry by day? _____
At what age was your child dry by night?_____

What problems, if any, were there with bowel and bladder control?

_____

_____

Were there any early separations from you?

_____

_____

Please list any illnesses and problems with hearing or vision that your child has/had.

_____

_____

What, if any, problems have there been with your child's behaviour?

_____

_____

Has your child ever been referred to a Child Psychologist/Psychiatry service? _____

What type of school does your child attend? _____

Do you currently have, or have you had, any concerns about your child's performance at school?

_____

Have there been any emotionally difficult experiences for your child?

_____

_____

FAMILY COMPOSITION

Please list the names and ages of your other children (and state if any are half or step brothers or sisters).

_____

_____

PARENTS' DETAILS

For each parent:	Father	Mother
Name:	_____	_____
Relationship (e.g. mother, step-mother etc.):	_____	_____
Age:	_____	_____
Occupation:	_____	_____

Please give any details of any medical or psychiatric problems you or your family of origin may have had.

_____

_____

_____

Please feel free to mention anything else you would like to bring to our attention.

_____

_____

_____

_____

Signed: _____ Name: _____ Date: _____

Appendix E
Premorbid School Report

University of Cape Town

Department of Psychology
Neuropsychology Rehabilitation Service Research

SCHOOL REPORT FORM

GENERAL COMMENTS: Please write as fully as you wish about this child and his/her problems.

Please also comment on the items overleaf, unless covered above.

What is the child's main problem as you see it?

For how long have these problems existed? Have there been other noticeable changes?

Attendance (Please comment if attendance has not been regular and reasons)

How long has the child been at the present school?

General Physical Health (Please comment if the child has any disability or health problems)

Other Agencies (Any other agencies involved with the child at present or recently)

Child's Family (Please give any information you think may be relevant)

Ability and Attainment

1. Estimated *general* ability: (Please tick)

Very much below average	Below average	Average	Above average	Very much above average

Any comments:

2. Attainment in Reading:

Very much below average	Below average	Average	Above average	Very much above average

Please give details and date of any recent reading tests:

Any comments on reading:

3. Attainment in Spelling:

Very much below average	Below average	Average	Above average	Very much above average

Please give details and date of any recent spelling tests:

Any comments on spelling:

4. Attainment in Writing:

Very much below average	Below average	Average	Above average	Very much above average

Any comments on pencil grip, letter formation etc.:

5. Attainment in Mathematics:

Very much below average	Below average	Average	Above average	Very much above average

Any comments on Mathematics:

6. Attainment in content subjects (History, Geography, Science, etc.):

Very much below average	Below average	Average	Above average	Very much above average

Any comments:

7. Attainment in Art:

Very much below average	Below average	Average	Above average	Very much above average

Any comments on artistic ability, constructional tasks and fine motor abilities:

8. Attainment in Sports:

Very much below average	Below average	Average	Above average	Very much above average

Any comments on sporting ability and gross motor abilities?

Personality, attitudes and adjustment: (Please comment on the child's relationship to other children and to adults and behaviour in and out of class.)

Mood/Emotions: (Please describe the child's usual mood/emotions and comment on any noticeable changes.)

What has already been tried in an attempt to help?

Which approach have you found most helpful so far?

What reasons can you suggest for any difficulties?

What do you think are the needs of this child and how may he/she be helped?

Details of person completing this form

Signature..... Name.....

Position held..... Date.....

Thank you very much for your help.

Appendix F
Star Chart

NAME:_____
