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A LONGITUDINAL INVESTIGATION OF NEUROPSYCHOLOGICAL AND
FUNCTIONAL OUTCOME AFTER COMPLICATED MILD TRAUMATIC BRAIN
INJURY

by
Shauna Kashluba

A Dissertation
Submitted to the Faculty of Graduate Studies
through the Department of Psychology
in Partial Fulfillment of the Requirements for
the Degree of Doctor of Philosophy at the
University of Windsor

Windsor, Ontario, Canada
2008

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Abstract

The current study investigated the extent to which neuropsychological and functional outcome after complicated mild traumatic brain injury (MTBI) parallels that of moderate traumatic brain injury (TBI) recovery. A longitudinal design was employed to compare the neuropsychological and functional status of individuals with complicated MTBI and moderate TBI at discharge from inpatient rehabilitation and at 1-year post-injury. The complicated MTBI group was comprised of 102 participants, each with an intracranial brain lesion documented via neuroimaging and a highest Glasgow Coma Scale (GCS) score in the Emergency Department between 13 and 15. The moderate TBI group was comprised of 127 participants, each with a highest GCS score in the Emergency Department between 9 and 12. The outcome measures of interest included the Functional Independence Measure, Disability Rating Scale, Community Integration Questionnaire, Logical Memory Test I and II, Rey Auditory Verbal Learning Test, Trail Making Test (A and B), Controlled Oral Word Association Test, Oral Symbol Digit Modalities Test, Wisconsin Card Sorting Test, and the Block Design Test. Statistical analysis revealed few differences in neuropsychological performance between the TBI groups. Qualitative examination of levels of cognitive impairment revealed less severely impaired information processing speed and verbal learning in the complicated MTBI group at rehabilitation discharge and at 1-year post-injury. Despite overall improvement across cognitive domains within the complicated MTBI group, some degree of impairment remained at 1-year post-injury on those measures identified as impaired soon after injury. No differences on measures of functional ability were found between the TBI groups at either time period post-injury, with both groups exhibiting incomplete recovery

of functional status at the 1-year follow-up. Overall, sufficient parallels in outcome after complicated MTBI and moderate TBI were found to indicate that when classifying severity of TBI based on GCS scores, consideration of a moderate injury designation should be given to persons with an intracranial bleed and a GCS score between 13 and 15.

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Introduction

Traumatic brain injury (TBI) represents a substantial public health problem and is a leading cause of death and disability in North America. Annually, an estimated 1.5 million Americans sustain a TBI, among whom approximately 50,000 die, representing one-third of all injury-related deaths in the United States (Sosin, Sniezek, & Thurman, 1996; Sosin, Sniezek, & Waxweiler, 1995). According to the Centers for Disease Control and Prevention (CDC) the estimated incidence of TBI associated with hospitalization in the United States is 79 per 100,000 population, with up to 90,000 of individuals experiencing associated long-term disability each year (CDC, 2006). Similarly, there are approximately 300,000 hospital admissions annually for persons with mild or moderate TBI (National Institutes of Health Consensus Developmental Panel on Rehabilitation of Persons With Traumatic Brain Injury [NIH], 1999). However, the estimated incidence of TBI is conservative given that many individuals who sustain more mild head injuries may never seek medical attention following injury. Unintentional falls, motor vehicle collisions (MVC), and assaults are the current leading contributors to TBI-related hospitalizations, with the highest incidence of TBI occurring among individuals aged 15 to 24 years and 75 years or older (CDC; NIH). Additionally, regardless of age or cause of injury, TBI is approximately two times more prevalent among males (CDC).

The burden associated with TBI is far-reaching, ranging from the afflicted individual with TBI to the society at large. As highlighted by the NIH (1999), TBI places a substantial burden on society due to its primary (e.g., medical costs) and secondary (e.g., lost productivity) effects. The consequences of TBI include a significant change in the individual's life-course, a profound disruption to the family unit, an extreme loss of

income or earning potential, and additional costly lifetime expenses. Individuals who sustain a TBI depend upon a multitude of healthcare services following injury due to impairment of physical, cognitive, and psychosocial functioning, for which the length of treatment and care is often long-term. A study of the direct cost associated with head injuries estimated the annual economic burden in the United States at nearly \$38 billion including \$4.5 billion for direct expenditures for hospital care, extended care, and other medical care and services; \$20.6 billion in injury-related work loss and disability; and \$12.7 billion in lost income from premature death (Max, MacKenzie, & Rice, 1991). Although difficult to measure, additional costs are also associated with the economic burden to caregivers of individuals with TBI who frequently forego earnings in order to care for the individual with TBI.

The alarming prevalence estimates of TBI, in combination with the widespread associated psychosocial and economic costs, have contributed to the relatively recent surge of research interest in the area of traumatic brain injury. In fact, research focused on clinical care and rehabilitation following TBI did not begin to flourish until the late 1970s, with some suggesting that the beginnings of interest in TBI can be dated to 1979 with the founding of the National Head Injury Foundation in the United States (NHIF; Gordon et al., 2006). Since then, significant advancements in such areas as the epidemiology, pathophysiology and mechanisms of injury, physiological, psychological and social factors related to recovery, and treatment/intervention efficacies following TBI have ensued.

A recent comprehensive review of the literature on the rehabilitation of individuals with TBI indicated that substantial advancements in the development of

methods to reliably and validly measure (i.e., quantify) certain aspects of post-TBI functioning have served a critical role in enhancing our understanding of this disorder (Gordon et al., 2006). Conversely, the same review highlighted the fact that no current metric exists that accurately characterizes the severity of brain injury in relation to the "...onset of specific impairments, the need for specific treatments, or to outcome" (Gordon et al., p.373). Thus, despite significant progress in this area, the metrics currently used to describe injury severity with respect to TBI do not clearly explicate the anticipated impairment, rehabilitation needs, or projected functional outcome. This is of particular importance within the field of clinical neuropsychology, whereby indices of injury severity following TBI serve as a guide for prognostication of cognitive and psychological functioning. Interestingly, the conventional classification of brain injury severity is not defined in terms of long-term outcome.

The dynamics of recovery from TBI are both complex and multifold; nonetheless, the ability to more reliably predict impairment and outcome based on injury severity following TBI is of critical importance for capitalizing on early interventions and ensuring the most appropriate long-term treatment planning. In this regard, a class of brain injury severity particularly lacking a thorough understanding of its associated cognitive impairment and functional outcome is that of complicated mild TBI. A review of the mechanics of TBI, followed by a review of the literature on the neuropsychological and functional implications of complicated mild TBI is herein provided within the context of its relation to other classes of brain injury severity. Research questions pertaining to outcome after complicated mild TBI are subsequently addressed within the current research study.

Mechanical Forces of TBI

Both the nature and severity of the force applied to the head are major factors influencing the resulting type of brain injury. Notably, head injury and brain injury are not synonymous. As highlighted by Reitan and Wolfson (2000), the following three scenarios are possible: head trauma without brain injury, head trauma with brain injury, and brain injury without a physical blow to the head (e.g., whiplash injuries). Head injury may be first classified as either (1) a closed head injury, whereby the head sustains a blunt force by striking against an object, or (2) a penetrating head injury, in which an object breaks through the skull to enter the brain parenchyma.

Closed Head Injury

The characteristic mechanisms most closely associated with closed head injury are those of static and dynamic loading (Graham, Adams, Nicoll, & Gennarelli, 1995). Static loading occurs when forces are gradually and slowly applied to the head, such as when the head is exposed to a heavy weight. Conversely, dynamic loading is associated with a rapid acceleration/deceleration of the brain and is more commonly the mechanical cause associated with closed head injury.

Acceleration-deceleration injuries occur when there is an impact with a moving head (e.g., head injuries resulting from falls and motor vehicle accidents), and can involve translational, rotational, and angular trauma to the brain. Translational acceleration represents linear acceleration along an axis that passes through the center of the head, whereby the center of gravity of the brain moves in a straight line. Isolated translational injury is rare, and usually occurs in combination with rotational injury (Yeates, 2000). Rotational acceleration involves rotation of the head around the center of

gravity of the brain, without movement of the center of gravity itself. Finally, angular acceleration comprises a combination of translational and rotational acceleration and represents the most commonly encountered type of head movement in clinical cases of TBI (Gennarelli, 1993). The duration of dynamic loading has been shown to be a significant factor in the severity of the ensuing brain injury (Morales et al., 2005; Stalhammer et al., 1987).

Dynamic loading may also be separated into two types, namely, (1) impulsive loading or (2) impact loading. Impulsive dynamic loading refers to instances where the head is set into motion rapidly or when the head is brought to a sudden stop without being struck, thus leading to inertial forces that cause injury to the brain (Morales et al., 2005). In contrast, impact dynamic loading occurs when a blunt object strikes the head, and is typically associated with both inertial and contact forces (Graham et al., 1995). Both impulsive and impact dynamic loading forces lead to tissue strain (i.e., the amount of deformation experienced by the brain parenchyma due to forces applied against it; Graham et al.).

Penetrating Head Injury

Penetrating head injury is most commonly caused by gunshots, whereby a fracture of the skull occurs as the bullet penetrates, with subsequent fragments of bone and the missile itself often entering the brain to cause additional damage (Morales et al., 2005; Reitan & Wolfson, 2000). The extent of injury resulting from a penetrating head injury is correlated with the mass, shape, direction of travel, and the velocity of the missile (Morales et al., 2005; Reitan & Wolfson). Similarly, shock waves caused by the velocity of the impact may cause brain tissue damage that is much more extensive than the area

represented by the tract of the wound (Reitan & Wolfson). Despite high mortality rates secondary to penetrating head injury, those who survive generally exhibit clinically significant improvements in their functional independence following inpatient rehabilitation (Stone, Lichtor, Fitzgerald, Barrett, & Reyes, 1995; Zafonte, Wood, Harrison-Felix, Millis, & Valena, 2001).

Skull Fractures

Skull fracture is not synonymous with brain injury, although certain types of skull fractures are associated with increased risk of secondary cranial nerve and vascular injuries, as well as direct brain injury. CT scanning is the criterion standard modality for diagnosis of skull fractures. Fractures of the skull are classified as linear or depressed. A full schematic classification of skull fracture types is presented in Appendix A.

Depressed skull fractures may be open or closed and result from a high-energy blow to a small surface area of the skull delivered via a blunt object. Aside from direct injury to the brain from the depressed free piece of bone, associated dural tears, seizures, and risk of infection complicate depressed skull fractures (Qureshi & Harsh, 2006). Indications for surgical elevation of a depressed fracture include when the depressed segment is more than 5 mm below the inner table of the adjacent bone, or when there is intracranial contamination, dural tear with pneumocephalus (i.e., air within the epidural or subdural space), or an underlying hematoma (Qureshi & Harsh).

Linear skull fractures result from a low-energy blunt trauma over a wide surface area of the skull. Linear skull fractures run through the entire thickness of the bone and are of little significance except when they course through a vascular channel, venous sinus groove, or suture, thus increasing the chances of a resulting epidural hematoma,

venous sinus thrombosis or occlusion, and sutural diastasis, respectively (Qureshi & Harsh, 2006). Simple linear fractures represent the most common type of skull fracture, with most patients presenting as asymptomatic and without loss of consciousness (LOC; Qureshi & Harsh).

Basilar skull fracture represents a linear fracture found at the base of the skull and is typically associated with dural tear. Basilar skull fractures can be further classified as temporal, sphenoid, occipital condylar, or cranial fossa type. Temporal bone fracture is very common, representing approximately 75% of all basilar skull fractures, and up to 48% of all skull fractures (Qureshi & Harsh, 2006). Depending on the location of the fracture, cranial nerve damage is not uncommon in basilar fractures. Neurologically intact patients with linear basilar fractures are typically managed conservatively (Qureshi & Harsh).

Primary and Secondary Brain Injury Mechanisms

Primary and secondary brain injury mechanisms represent a second organizational method of classifying injuries resulting from head trauma. Primary brain injuries result directly from the traumatic forces to the head that disrupt brain tissue (i.e., biomechanical causes of injury) and include skull fractures, contusions and hemorrhages, and shear-strain injury. Secondary injuries arise indirectly from the trauma and take a certain, albeit relatively short, amount of time to develop following the injury. Secondary injuries include cerebral edema, hypoxia and hypotension, increased intracranial pressure, seizures, and mass lesions (see Appendix B).

As highlighted by Morales et al. (2005), the overall incidence of primary brain injuries has decreased in recent years due to the increased usage of preventative measures

such as safety equipment (e.g., air bags in vehicles, helmets) and through increased enforcement of laws enhancing individual and public safety (e.g., mandatory use of seatbelts). In most instances, medical management of TBI is focused on the prevention or control of secondary mechanisms of brain injury given their potential to significantly impact outcome (Yeates, 2000). Similarly, due to their delayed onset and often gradual progression over hours, days, and even weeks after the initial trauma, secondary mechanisms of brain injury are potentially more amenable to post-injury therapeutic intervention than are primary brain injuries (Morales et al.).

Focal and Diffuse Brain Injury

Lesions resulting from traumatic brain injury can be further classified as either focal or diffuse, and apply to both primary and secondary brain injuries. Damage from focal brain injury tends to occur in the direct vicinity of the mechanical input to the head and implicates the underlying cortical, and in more severe cases of TBI, subcortical structures (Laurer, Meaney, Margulies, & McIntosh, 2002). Examples of focal brain injuries include extradural and subdural hematomas, intracerebral hematomas, and fracture and coup-contracoup cerebral contusions (i.e., areas of hemorrhage that form around small blood vessels). Specifically, extradural hematoma occurs due to a hemorrhage from damaged meningeal blood vessels where the resulting hematoma enlarges and gradually strips the dura from the skull, whereas subdural hematoma occurs when the bridging veins are ruptured. In contrast, intracerebral hematomas are unrelated to the surface of the brain and are instead caused by the rupture of intrinsic blood vessels within the brain at the time of injury (Graham, Gennarelli, & McIntosh, 2002). Finally, coup contusions arise from the local bending of the skull when it exceeds the tolerances

of the pia, vascular, and cortical brain tissue at the site of injury (Graham et al.); whereas deformation exceeding the maximum threshold of elasticity of the calvarium results in an actual skull fracture (Morales et al., 2005). Contracoup contusions develop on the side of the brain opposite the point of impact. In general, contusions tend to involve parts of the brain that are more susceptible to damage from bony irregularities within the skull. Common sites for contusions following head injury include the frontal and temporal poles, the orbital surface of the frontal lobes, the inferior-lateral surface of the temporal lobes, the superior medial aspect of both cerebral hemispheres, and the gyri on either side of the Sylvian fissure (Reitan & Wolfson, 2000).

In contrast to focal injuries, diffuse brain injuries result primarily from tissue distortion or tissue shear caused by inertial forces present at the time of injury (Gennarelli, 1993; Maxwell, Povlishock, & Graham, 1997). Diffuse injuries are commonly separated into four main pathologies: diffuse axonal injury (DAI), hypoxic injury secondary to increased intracranial pressure or reduced arterial pressure, diffuse brain swelling due to an increase in the cerebral blood volume or water content of the brain tissue, and diffuse vascular injury (Graham et al., 2002).

DAI is the primary pathological feature of TBI regardless of type (Kushner, 1998; Povlishock, Erb, & Astruc, 1992), and DAI represents the predominant mechanism of injury in 40-50% of TBIs requiring hospitalization (Meythaler, Peduzzi, Eleftheriou, & Novack, 2001). An increase in the distribution and number of axons involved is associated with increased severity of brain injury, and the extent of axonal injury is suggested by duration of LOC (Alexander, 1995; Povlishock et al.; Smith, Meaney, & Shull, 2003). DAI comprises an evolving morphological change in axons after injury

(e.g., axonal swelling, formation of retraction balls, myelin degeneration), such that the change process continues over hours and days following injury. Axonal damage in the white matter is particularly common in midline structures such as the splenium of the corpus callosum and the brain stem (Smith et al.). Similarly, DAI with involvement of white matter tracts has been shown to be a significant contributor to subsequent neurological and cognitive impairment in TBI survivors, and has been found upon autopsy in TBI cases ranging from mild to severe (Blumbergs et al., 1995; Graham et al., 1995; Maxwell et al., 1997; Reitan & Wolfson, 2000).

The traumatic injury to the axons leads to the disconnection between various target sites in the central nervous system, which is assumed to translate into the resultant impairment and morbidity (Maxwell et al., 1997; Meythaler et al., 2001). Given that the mechanism of injury associated with DAI is microscopic, individuals who have sustained a TBI with DAI may have only minimal changes noted on computed tomography (CT) or magnetic resonance imaging (MRI) scans (Meythaler et al.). Moreover, it is argued that DAI may be significantly underdiagnosed in brain injury of milder severity due to the lack of sensitivity of current imaging techniques to detect subtle brain pathology (Smith et al., 2003). Ultimately, an unequivocal diagnosis of DAI can only be established upon autopsy. MVCs are the major cause of DAI (Meythaler et al.), and a component of DAI is believed to be present in all MVCs where the individual has lost consciousness (Whyte & Rosenthal, 1993).

As highlighted by Yeates (2000), recent advances in the neurochemistry of brain injury have suggested that DAI is mediated by a cascade of biochemical reactions that occur over an extended period of time following injury and represent the central nervous

system's inability to respond to increasing energy demands. That is, neurochemical mechanisms following head trauma such as a breakdown of sodium-potassium pumps, the production of free radicals and excitatory neurotransmitters (e.g., glutamate), and a reduction in cerebral blood flow due to disruption of normal calcium homeostasis by hypoxia-ischemia act to further exacerbate the effects of brain injury. Moreover, experimental research with animals has shown that mechanical disruption of axons is not necessary for axonal injury, but rather DAI can result directly from neurochemical reactions following head trauma without evidence of mechanical axonal tearing (Novack, Dillon, & Jackson, 1996).

It has been suggested that the degree of disruption to the brain's normal biochemical processes is associated with the severity of injury, such that a temporary change in cerebral neurochemical mechanisms may be related to the transient clinical manifestations accompanying mild brain injuries (Smith et al., 2003). Hence, whereas actual *destruction* of axons due to shearing forces occurs with increasing TBI severity, it is hypothesized that the clinical manifestations apparent in the acute phase after mild TBI (e.g., fatigue, dizziness, headache, subtle neurocognitive impairments) are due to axons rendered temporarily *dysfunctional*, but not destroyed (Novack et al., 1996; Smith et al.; Yeates, 2000).

Thus, the extent of DAI following closed-head injury is considered a critical determinant of the severity of overall outcome including death, the duration of a comatose state, or the degree of overall impairment after less severe TBI (Graham et al., 2002; Novack et al., 1996). However, studies continue to demonstrate that the use of conventional imaging techniques in determining the extent of DAI is a poor predictor of

the functional outcome of individuals with TBI (Diaz-Marchan, Hayman, Carrier, & Feldman, 1996; Smith et al., 2003). Particularly problematic is the lack of sensitivity of conventional imaging techniques to detect more subtle axonal pathology, such as that which may occur in less severe TBI where duration of LOC is minimal or negligible.

New imaging techniques being developed may better depict brain regions with axonal pathology. These include the MRI techniques of diffusion weighted imaging and magnetization transfer imaging, both of which take advantage of the molecular disarrangement of the white matter tracts associated with diffuse axonal pathology (Smith et al., 2003). Despite the increased sensitivity and accuracy of MRI to diagnose cerebral pathology, CT scanning remains the gold standard for the detection of intracranial abnormalities and is the recommended imaging technique for the management of closed-head injured patients in the acute stage (American College of Surgeons Committee on Trauma, 1986; Toyama et al., 2005). In the United States, patients with an admission Glasgow Coma Scale (GCS) score of 14 or less routinely undergo CT scanning (Jeret et al., 1993); however, CT scans are standard procedure in some healthcare systems' clinical pathways following all instances of head injury, regardless of the level of severity of injury (Iverson, Lovell, & Smith, 2000).

Classification of TBI Severity

TBI represents a heterogeneous disorder and is associated with a diverse clinical population, in large part due to the variable nature of injuries to the brain. Injury severity following TBI has been assessed using a variety of metrics including duration of LOC, depth of coma, and length of post-traumatic confusion (PTC) (i.e., the time period from when the person regains consciousness until he or she regains the capacity for continuous

memory; Mittenberg & Strauman, 2000). To date, neuroimaging has not played a role in standard methods of classifying the severity of TBI. Based upon a variety of measures of injury severity, brain injury has conventionally been classified as mild, moderate, or severe. Notably, there exist no universally accepted criteria or definition for classifying TBI.

The most commonly used measure of brain injury severity is the Glasgow Coma Scale (Teasdale & Jennett, 1974); a metric originally designed for the assessment of the level of consciousness after brain injury (i.e., depth of coma). GCS scores range from 3 to 15, with scores from 13 to 15 typically representing "mild" injuries, scores from 9 to 12 representing "moderate" injuries, and scores of 8 or less representing "severe" injuries (see Appendix C). According to this classification system, mild TBI (MTBI) represents the most common type of brain injury. For example, based exclusively on the GCS score as the index of brain injury severity, Narayan and colleagues (2002) found that over the course of a one year period approximately 10% of brain injuries in the United States were classified as severe upon hospital admission, 10% as moderate, and the remaining 80% as mild.

In 1993, the Mild Traumatic Brain Injury Committee of the Head Injury Interdisciplinary Special Interest Group of the American Congress of Rehabilitation Medicine published an operational definition of MTBI that is widely used in the literature as a means of diagnosing MTBI. The definition includes any manifestation of the following: (1) any loss of consciousness; (2) amnesia involving the events immediately before or after the injury; (3) any alteration in mental state at the time of injury; and (4) focal neurological deficits. In addition, the definition states that the severity of injury

must not exceed an initial GCS score of 13-15, and the duration of PTC and LOC should not exceed 24 hours or 30 minutes, respectively. Notably, evidence from radiological imaging of extracranial or intracranial damage is not included in the definition. The term "concussion" is used synonymously with MTBI in the literature, and similarly implies a transient disturbance of neuronal functioning secondary to mechanical forces acting on the brain (Kushner, 1998).

The distinction between moderate and severe TBI has not been as clearly delineated in the literature compared to that of MTBI, although an overwhelming majority of the research to date has relied on initial GCS scores following injury as the principal method by which to differentiate moderate and severe injuries (i.e., moderate TBI initial GCS of 9-12 vs. severe TBI initial GCS of 8 or less). However, as Vitaz and colleagues highlight, individuals with moderate TBI represent a particularly challenging brain injury population given the considerable variability of trauma severity, hospital course, neurological recovery, cognitive deficits, and residual sequelae (Vitaz, Jenks, Raque, & Shields, 2003). That is, given the range of GCS scores that define moderate TBI, individuals with this degree of TBI severity vary with respect to their overall level of impairment following TBI. Despite the precise GCS upper and lower score boundaries for moderate TBI, a trend in the literature has been to combine moderate TBI with either mild TBI (e.g., mild-to-moderate TBI) or with severe TBI (e.g., moderate-to-severe TBI). A detrimental consequence of combining moderate TBI with other classes of brain injury severity is an overall paucity of information pertaining to outcome following moderate TBI (Vitaz et al.) and a lack of specificity regarding prognosis and outcome for uncomplicated and complicated MTBI (Kushner, 2002).

MTBI

In order to best comprehend, predict, and explicate outcome following a heterogeneous disorder such as TBI, an accurate classification and diagnosis of the specific disorder is essential. In keeping with this viewpoint, it has been suggested that the term *mild traumatic brain injury* may be a misleading diagnosis because it, much like moderate TBI, includes too large a spectrum of clinical manifestations, with clinical indicators ranging from mild transient symptoms to long-term disabling problems (Hsiang, Yeung, Ashley, & Poon, 1997; Iverson, 2005; Kushner, 2002; Servadei, Teasdale, & Merry, 2001; Uchino, Okimura, Tanaka, Saeki, & Yamaura, 2001; Williams, Levin, & Eisenberg, 1990; van der Naalt, van Zomeren, Sluiter, & Minderhoud, 1999). It has been argued that the term "mild" TBI be reserved for those cases of minor head injuries in which no significant consequences or long-term sequelae ensue (Hsiang et al., 1997).

Most studies to date indicate that the majority of individuals who sustain a MTBI, defined by a GCS score of 13-15, report essentially a full recovery. Specifically, although symptom complaints are common soon after MTBI, the vast majority of studies on long-term patient complaints indicate that MTBI symptoms are largely resolved within 3-months of injury (Alexander, 1995; Binder, Rohling, & Larrabee, 1997; Dikmen, McLean, & Temkin, 1986; Kashluba et al., 2004; Levin et al., 1987; Ponsford et al., 2000; Satz et al., 1999). The most common symptoms typically reported in the acute phase after MTBI include headache, fatigue, irritability, and forgetfulness (Gasquoine, 1997; Kashluba et al., Paniak et al., 2002; Ponsford et al.).

Despite the typical findings of symptom resolution following MTBI occurring within 3-months of injury, a small percentage of individuals complain of suffering from a number of physical, cognitive, and emotional sequelae persisting beyond the typical recovery time frame following MTBI, with some persons reporting difficulties even years later (Alexander, 1995; Kraus & Nourjah, 1988; Ponsford et al., 2000). Although prevalence rates for persistent sequelae are highly variable in the literature, the majority of studies report a rate for persistent symptomatology following MTBI of approximately 10%-15% (Alexander; Kraus & Nourjah). In light of this group of individuals with poorer outcome following a conventional GCS designation of MTBI, recent investigations have led to the proposal of a more precise classification of MTBI based on findings of heterogeneity in the pathophysiology among patients with GCS scores ranging from 13 to 15.

Complicated MTBI

Proponents of more restrictive diagnostic criteria for MTBI contend that heterogeneity of pathophysiological features exists among individuals with GCS scores of 13 to 15 to the extent that outcome should not be expected to be uniform across all individuals with MTBI (Culotta, Sementilli, Gerold, & Watts, 1996; Hsiang, 2005; Hsiang et al, 1997; Iverson, 2005; Levin, Williams, Eisenberg, High Jr., & Guinto Jr., 1992; Servadei et al., 2001; Stein & Ross, 1990; Williams et al., 1990). Similarly, it has been argued that conventional guidelines for evaluation of MTBI that rely primarily on neurological observation are not sufficient to accurately determine severity of injury (Stein & Ross, 1990). Pathophysiological features that may correlate with TBI severity that are not included in the conventional classification criteria for MTBI include the

location and extent of cortical contusions, intracranial hemorrhages, DAI, and skull fractures (Kushner, 2002). The terms "complicated mild traumatic brain injury" (Williams et al., 1990) or "high-risk mild head injury" (Hsiang, 1997) are becoming more commonly used to refer to those MTBI patients who may be at greater risk of experiencing poorer outcome compared to individuals with uncomplicated MTBI.

The division of MTBI into uncomplicated and complicated types is based on GCS scores and radiological findings. Williams et al. (1990) defined uncomplicated MTBI as requiring a GCS of 13-15 with a normal CT scan and *either* a normal skull x-ray *or* an abnormality limited to a linear basilar skull fracture. Alternatively, the authors defined complicated MTBI as including a GCS of 13-15 *with* radiological evidence of a focal brain lesion, depressed skull fracture, or both. In contrast, Hsiang et al. (1997) defined MTBI as including a GCS of 15 with no acute radiographic abnormalities, whereas high-risk MTBI was defined as a GCS of 13-14 *or* a GCS of 15 with acute radiological abnormalities. Abnormal radiological findings were defined as skull fracture, intracranial hematoma or contusion, or subarachnoid hemorrhage. Two major differences between these classifications are evident. First, Hsiang and colleagues designate GCS scores of 13 and 14 automatically as high-risk, regardless of imaging results. Secondly, Hsiang et al. describe all individuals with skull fractures as having high-risk MTBI, irrespective of their GCS score within the 13-15 range.

Similarly, Servadei and colleagues (2001) proposed a more detailed classification for MTBI based primarily on the risk of associated intracranial hematoma. Specifically, they defined MTBI as a GCS of 14 or 15, *excluding* patients with GCS of 13 due to their relatively higher risk of intracranial lesions. Within the MTBI patient population with

GCS of 14 or 15, the authors describe three levels of risk: (1) a "low risk" group defined as patients with a GCS of 15 on admission but without history of LOC, amnesia, vomiting, or diffuse headache; (2) a "medium risk" group defined as patients presenting with a GCS of 15 but with one or more of LOC, amnesia, vomiting, or diffuse headache; and (3) a "high risk" group defined as patients with an admission GCS of 14, or an admission GCS of 15 with a skull fracture and/or neurological deficits. Also included within the high risk group are patients with an admission GCS of 15 with or without clinical findings, absent neurological deficits and skull fracture, but with at least one risk factor including coagulopathy, drug or alcohol consumption, previous neurosurgical procedures, pretrauma epilepsy, or age over 60 years. Appendix D provides a summary of current MTBI subclassifications.

To date, a relatively modest number of studies have been conducted investigating differences in injury severity among MTBI patients as measured by GCS scores and radiological findings. Culotta and colleagues (1996) examined the relationship of admission GCS scores to radiological variables indicative of injury severity in an attempt to substantiate the then-widely held assumption of homogeneity of injury severity among a large sample of patients meeting conventional diagnostic criteria for MTBI (i.e., MTBI criteria as defined by the American Congress of Rehabilitation Medicine, 1993). Significant differences in severity of head injury among patients with admission GCS scores of 13 through 15 were found. Specifically, patients admitted to the Emergency Department (ED) with GCS scores of 13 were significantly more likely to have intracranial lesions demonstrated on CT scanning and were more likely to require neurosurgical intervention within the first 24 hours than were those admitted with GCS

scores of 14 or 15. Likewise, significant findings regarding lesion frequency and the need for surgical intervention were also evidenced for patients admitted with GCS scores of 14 versus those with GCS scores of 15. Finally, although not statistically significant, cranial fractures were more prevalent among patients with lower GCS scores. Similarly, in an earlier study Dacey and colleagues showed the need for neurosurgical intervention secondary to MTBI increased by a factor of 20 in the presence of cranial fracture (Dacey, Alves, Remil, & Jane, 1986).

Stein and Ross (1990) examined the utility of CT scans for identifying intracranial injuries not apparent upon initial clinical evaluation of MTBI patients in the ED. Results showed that the frequency of positive imaging findings was higher in patients with lower GCS scores. Within the overall MTBI sample, 18% of patients had abnormalities upon CT scanning. In particular, 40% of patients with a GCS of 13 (i.e., 25 of 62 patients), 23% of patients with a GCS of 14 (i.e., 32 of 142 patients), and 13% of patients with a GCS of 15 (i.e., 59 of 454 patients) had abnormal CT findings. Moreover, 13% of the patients with a GCS of 13 required intracranial surgery.

It is clear that intracranial abnormalities exist in a proportion of individuals who meet conventional criteria for MTBI. Although the base rate of abnormal radiological imaging in this clinical population varies according to GCS scores employed in defining MTBI, the range is approximately 7% (Ivanez et al., 2004) to 18% (Stein & Ross, 1990). Certainly, the introduction of radiological imaging has improved the management of head injury. However, disagreement exists with respect to determining which head injured persons should routinely undergo cranial CT scanning, particularly in light of the

associated financial burden (e.g., all patients with head injury regardless of GCS score versus only patients with a GCS score of less than 15, etc.).

The use of radiological findings (e.g., X-ray, CT scan, MRI scan) in the sub-classification of MTBI represents an attempt to objectively identify individuals with intracranial abnormalities that place them at risk for poor outcome despite what appears to be a relatively mild injury. Although much research has been conducted investigating acute post-head injury clinical manifestations in an attempt to identify MTBI patients with or at risk of developing intracranial abnormalities, the findings have been quite variable. Disagreement continues with respect to the predictive utility of risk factors such as duration of LOC, length of PTC, headache, nausea and vomiting, cranial soft tissue injury, acute posttraumatic seizures, acute drug or alcohol intoxication, chronic alcoholism, mechanism of injury, and previous intracranial operations. Discrepancies among findings are primarily attributed to methodological limitations including variability in diagnostic criteria for MTBI, poor outcome measures, and small sample sizes (Ivanez et al., 2004; Jeret et al., 1993).

In a recent investigation, Ivanez and colleagues (2004) conducted an in-depth analysis of clinical risk factors in a large sample of MTBI patients with the aim of determining which risk factors, if any, were predictive of the presence of intracranial lesions as identified by CT scan. MTBI was defined by a GCS score of 14 or 15 in the ED, with or without LOC. Statistical prediction models failed to achieve 100% sensitivity in the detection of MTBI patients with CT scans positive for intracranial lesions within reasonable specificity limits. However, the authors concluded that a GCS score of 14, loss of consciousness, vomiting, headache, signs of basilar skull fracture, neurological

deficit, coagulopathies, hydrocephalus treated with shunt insertion, associated extracranial lesions, and patient age greater than 65 years were significant independent risk factors indicating the need for CT scanning following MTBI. The incidence of acute intracranial lesions in the overall sample was 7.5%.

In a similar study, Jeret and colleagues (1993) investigated clinical predictors of abnormal CT scan findings following MTBI, restricting the sample to include only patients with a presenting GCS of 15 who experienced a brief LOC or PTC. Nine percent of the overall sample ($N= 712$) had abnormalities upon CT, with 48% of those patients exhibiting multiple abnormalities. Four clinical factors were associated with abnormal CT scan findings: older age, White race, signs of basilar skull fracture, and mechanism of injury (i.e., either being a pedestrian hit by a motor vehicle or a victim of an assault). However, no single item or combination of items could be used to classify 95% of the patients into either the normal or abnormal CT group. Similarly, sex, duration of LOC or PTC, performance on forward and reverse digit span, object recall, focal abnormality on a general clinical neurological exam, and subjective complaints were not statistically correlated with CT abnormality. Nonetheless, Jeret et al. and others (e.g., Vollmer & Dacey, 1991) highlight the findings that patient presentation characterized by a GCS score of 15 and a brief LOC or PTC does not preclude the existence of focal neurological signs, and that such patients may still harbour intracranial lesions.

In summary, findings from a modest but increasing literature confirm that the conventional classification of MTBI encompasses a heterogeneous population of patients, with a small but clinically significant group suffering more severe injuries. Studies to date have routinely demonstrated that CT scanning abnormalities are evidenced across

the entire range of GCS scores designated as MTBI, with an increased rate of intracranial abnormality exhibited as GCS scores decrease from 15 to 13. Likewise, the need for neurosurgical intervention has been shown to increase with a decrease in GCS scores and with the presence of cranial fractures. Although clinical predictors of abnormal imaging after MTBI remain largely unsubstantiated, duration of LOC and PTC, signs of basilar skull fractures, and age over 65 appear to be the most strongly correlated with positive imaging. Thus, the division of MTBI into subgroups of complicated versus uncomplicated patients appears to be congruent with pathophysiological findings.

Cognitive Sequelae of Traumatic Brain Injury

Extensive evidence exists demonstrating that TBI is associated with numerous cognitive impairments. Likewise, it is universally accepted that the degree of neuropsychological impairment is greater with increased severity of brain damage. This was most effectively demonstrated by Dikmen and colleagues who found a clear dose-response relationship between length of coma (i.e., time to follow commands as measured by the highest score obtained on the motor component of the GCS) and level of performance on a comprehensive battery of neuropsychological measures at 1-year post-TBI (Dikmen, Machamer, Winn, & Temkin, 1995). Specifically, increases in severity of TBI yielded significantly worse neuropsychological performance in comparison to trauma controls. Additionally, neuropsychological performance by the subgroup with the mildest injury, defined as time to follow commands less than 1 hour, did not differ significantly from non-head injured trauma controls.

Neuropsychological Consequences of MTBI

The neuropsychological consequences of MTBI (i.e., GCS scores of 13-15 inclusive) have been well documented, with most studies confirming at worst deficits in the domains of attention, learning and memory, and information processing speed in the first few days following MTBI, with demonstrable spontaneous recovery in most patients by 1-3 months post-injury (Binder, 1986; Binder et al., 1997; Dikmen et al., 1986; Gentilini et al., 1985; Kashluba et al., 2004; Levin et al., 1987; Lovell, Collins, Iverson, Johnston, & Bradley, 2004; Macciocchi, Barth, Alves, Rimel, & Jane, 1996; Ponsford et al., 2000). Similarly, numerous recent studies investigating concussion in sports have found consistent results, such that concussed athletes recover quickly and completely in terms of both perceived symptoms and cognitive performance (Iverson, 2005). For instance, McCrea et al. (2003) conducted a large-scale prospective controlled study of collegiate football players comparing pre-season baseline testing results with post-injury results in those athletes who sustained a concussion. Compared to uninjured controls, balance problems resolved in 3-5 days, perceived symptoms resolved in 7 days, and cognitive functioning improved to baseline within 5-7 days of injury in concussed athletes.

Similarly, a recent review of the literature by the World Health Organization (WHO) Collaborating Centre Task Force on Mild Traumatic Brain Injury concluded that in terms of objectively measured cognitive deficits, the best evidence suggests there are no MTBI-attributable cognitive deficits beyond 1-3 months post-injury in the majority of cases (Carroll et al., 2004). Indeed, those studies reporting overall impaired neuropsychological performance at least 3-months post-MTBI are deemed

methodologically flawed due to inadequate or lack of comparison groups (e.g., Alves, Macciocchi, & Barth, 1993; Barth et al., 1983; Rimel, Giordani, Barth, Boll, & Jane, 1981), small sample sizes (e.g., Hugenholtz, Stuss, Stethem, & Richard, 1988), or high rates of attrition (e.g., Alves et al.).

Furthermore, none of the studies reviewed by the WHO Task Force on MTBI found an association between LOC and increased deficits in cognitive functioning after MTBI (e.g., Iverson et al., 2000; Lovell, Iverson, Collins, McKeag, & Maroon, 1999; McCrory, Ariens, & Berkovic, 2000). For example, Iverson and colleagues (2000) divided a large group of uncomplicated MTBI patients in the acute recovery phase into three groups on the basis of LOC: positive LOC, negative LOC, or equivocal LOC. All patients were administered a brief neuropsychological battery within 1-week of injury. No significant differences among the groups were found on any of the measures of attention, learning and memory, language, or executive functioning.

In contrast, the growing literature on concussion in sports has revealed an increased vulnerability to neuropsychological deficits following multiple concussions (Collins et al., 1999; Gronwall & Wrightson, 1975; Iverson, Gaetz, Lovell, & Collins, 2004; Matser, Kessels, Lezak, & Troost, 2001; Wall et al., 2006). In particular, studies of amateur athletes suggest that sustaining three or more concussions is associated with small but measurable neuropsychological impairment (Collins et al., 2002; Gaetz, Goodman, & Weinberg, 2000; Iverson et al., 2004). Furthermore, the term "second impact syndrome" has been used to describe a concussion that occurs while the individual is still symptomatic from a previous concussion, and is hypothesized to result in dysfunction of cerebrovascular autoregulation with associated progressive cerebral

edema that may be detectable upon CT imaging (Kelly et al., 1991; Kelly & Rosenberg, 1997).

Neuropsychological Consequences of Complicated MTBI

In comparison to the more inclusive classification of MTBI comprising all head-injured patients with a GCS ranging from 13-15, a paucity of research has been conducted on the neuropsychological functioning of individuals with complicated MTBI. Among those studies investigating the cognitive implications of complicated MTBI, the findings suggest that these individuals demonstrate more severe neuropsychological sequelae than individuals with uncomplicated MTBI.

Williams and colleagues (1990) were among the first to demonstrate differences in neuropsychological functioning between uncomplicated and complicated MTBI by comparing three groups of head injured patients: patients with uncomplicated MTBI (GCS of 13-15); patients with MTBI (GCS of 13-15) complicated by a brain lesion or depressed skull fracture; and patients with a moderate TBI with or without positive radiological findings (GCS of 9-12). No differences were found between the uncomplicated and complicated MTBI groups with respect to duration of LOC or PTC, whereas the moderate TBI group had longer durations on both measures. Conversely, neuropsychological functioning assessed upon resolution of PTC was impaired in the complicated MTBI and moderate TBI groups in comparison to the uncomplicated MTBI group, as measured by performances on word generation, information processing speed, and visual memory tasks. Similarly, global outcome at 6 months post-injury was better in the uncomplicated MTBI group than in the complicated MTBI and moderate TBI groups, as measured by the Glasgow Outcome Scale (GOS; Jennett & Bond, 1975). Thus, despite

comparable findings on head injury severity variables such as duration of LOC and PTC among the uncomplicated and complicated MTBI patients, the neuropsychological and outcome data revealed more similarities between the complicated MTBI and moderate TBI patients. Notably, MTBI patients with depressed skull fracture had better neuropsychological and global outcome than MTBI patients with intracerebral contusion or hematoma.

In a more recent study, Borgaro and colleagues investigated neuropsychological performance at 1-month post-injury in a small sample of uncomplicated and complicated MTBI patients matched on GCS score and sub-divided into groups according to the presence of space-occupying lesions upon CT or MRI scanning (Borgaro, Prigatano, Kwasnica, & Rexer, 2003). Cognitive assessment consisted of administration of the BNI Screen for Higher Cerebral Functions (BNIS; Prigatano, Amin, & Rosenstein, 1995), which includes measures of orientation, speech and language, attention, visuospatial/visual problem solving, and learning and memory. Results revealed that the complicated MTBI group performed significantly worse than uninjured controls on all cognitive measures, whereas the uncomplicated MTBI group were more similar to controls, performing worse on only the speech and language subtest.

Similar differences in cognitive functioning have been found in older adults with uncomplicated versus complicated MTBI. Goldstein and colleagues divided head injured patients aged 50 years and older into two groups: uncomplicated MTBI (i.e., GCS of 13-15 and negative radiological findings) and a mixed complicated MTBI and moderate TBI group (Goldstein, Levin, Goldman, Clark, & Kenehan-Altonen, 2001). The mixed TBI group consisted of four patients with moderate TBI and 13 complicated MTBI patients

with GCS scores of 13 to 15 and evidence of intracranial complications. Cognitive measures were administered approximately 1 - to 2-months post-injury. The mixed TBI group performed significantly worse than the uncomplicated MTBI group on seven of the ten cognitive measures assessing attention, expressive language, verbal and visual memory, and executive functioning. In keeping with previous investigations of MTBI, the uncomplicated MTBI group performed comparably to controls on all cognitive tasks, with the exception of a phonemic word generation task.

Despite a limited amount of research, the findings suggest that at least in the short-term post-injury, patients with complicated MTBI are indeed more impaired on neuropsychological measures compared to both uninjured controls and patients with uncomplicated MTBI. Injury severity variables such as duration of LOC and PTC do not appear to account for the differences in cognitive performance. Further research is required to determine whether neuropsychological outcome after complicated MTBI more closely approximates that of patients with moderate TBI.

Neuropsychological Consequences of Moderate to Severe TBI

An extensive amount of evidence exists confirming that more severe brain injury is associated with greater neuropsychological impairment. Three decades ago, Levin, Grossman, and Kelly (1976) were among the first to demonstrate a dose-response relationship between severity of brain injury and degree of neuropsychological deficit, particularly with respect to post-injury linguistic functioning. As abovementioned, Dikmen and colleagues (1995) have since replicated the dose-response relationship between severity of injury and neuropsychological performance at 1-year post-injury in a methodologically sound longitudinal study using trauma controls.

However, variability of cognitive impairment is also evidenced with increases in severity of brain injury. For example, Dikmen et al. (1995) found that patients with more than two weeks of coma (i.e., most severe group) showed diffuse and persistent impairments at 1-year post-injury, with substantially lower performances on all neuropsychological measures administered compared to TBI patients of lesser severity. Given the magnitude of neurological insult required to result in a coma of significant duration, long-term global cognitive impairments are not unexpected. Similarly, Kreutzer and colleagues found considerable variation among test performances in terms of the proportion of patients falling in the impaired range on a battery of neuropsychological measures at 1-month after moderate to severe TBI (Kreutzer, Gordon, Rosenthal, Marwitz, 1993). Clearly, neuropsychological recovery following moderate to severe TBI is not uniform across all individuals or cognitive domains. However, a pattern of neuropsychological deficits following moderate to severe TBI is frequently reported in terms of impairments in the domains of information processing speed, higher-level cognitive flexibility, and learning and memory functioning (Levin et al., 1990; Millis et al., 2001; Novack, Anderson, Bush, Meythaler, & Canupp, 2000; Ponsford, Oliver, & Curran, 1995).

With respect to time since injury, the vast majority of research reveals significant recovery in cognitive functioning within the first year following moderate to severe TBI (Dikmen, Machamer, Temkin, & McLean, 1990; Kersel, Marsh, Havill, & Sleight, 2001; Kreutzer et al., 1993; Levin et al., 1990; Novack et al., 2000). Recovery of neuropsychological functioning beyond 1-year post-injury is more specific and dependent on severity of injury. For example, in a longitudinal investigation of moderate to severe

TBI patients at 1-month, 1-year, and 2-years post-injury, Dikmen and colleagues (1990) found a marked improvement in cognitive functioning in the first year post-injury, with only modest recovery of cognitive functions in the second year. Moreover, despite recovery within the first year, persistent cognitive difficulties remained over the 2-year period with a significant association between length of coma and level of cognitive functioning. In a similar study, Millis and colleagues (2001) conducted an in-depth longitudinal investigation of neuropsychological outcome following moderate to severe TBI at 5-years post-injury. Significant variability in outcome 5-years post-injury was found, ranging from no impairment on neuropsychological measures in some individuals to severe impairment in other individuals. Specifically, using the Reliable Change Index, 22% of the TBI sample improved, 15% declined, and 63% remained unchanged with respect to neuropsychological performance. Furthermore, the subgroup evidencing improvement at 5-years post-TBI was the youngest, whereas the subgroup evidencing a decline in performance over time was the oldest. Despite heterogeneity of neuropsychological outcome, improvement was most evident on measures of cognitive speed, visuoconstruction, and verbal memory from 1-year to 5-years post-injury.

Patients' perceptions of their cognitive abilities following moderate to severe TBI are also in keeping with results from objective neuropsychological assessment. In a comprehensive self-report outcome study of predominantly severe TBI patients who received intensive multidisciplinary rehabilitation post-injury, Ponsford et al. (1995a) found a high proportion of patients reporting ongoing cognitive difficulties 2-years post-TBI. In particular, problems with memory (74%), word-finding (68%), speed of thinking (64%), concentration (62%), and planning/organization (48%) were commonly endorsed

by TBI survivors. Moreover, results of a 5-year follow-up study on the same sample revealed that patients' perception of their cognitive deficits remained consistent over time (Olver, Ponsford, & Curran, 1996). Notably, it is suggested that the findings may underestimate the true rate of cognitive difficulties given the lack of awareness of deficits common among individuals following severe TBI.

The extent of recovery of general intellectual functioning following moderate to severe TBI is also variable, although general intelligence appears to be less compromised after TBI compared to other cognitive domains. In an early study, Mandelberg and Brooks (1975) found no differences in composite scores between controls and patients with severe TBI on the Wechsler Adult Intelligence Scale 1-year post-injury. In contrast, individuals with severe TBI were found to have VIQ and PIQ values 14 and 22 points lower, respectively, than those of trauma controls at 1-year post-injury (Dikmen et al., 1995). The role of speeded tasks is highlighted as a significant factor contributing to more pronounced impairments of PIQ compared to VIQ. The most precise assessment of recovery of general intellectual functioning following TBI, in the absence of pre-injury intellectual assessment scores, requires a comparison of post-injury IQ with a valid estimate of pre-morbid intelligence. Using this approach, Kersel et al. (2001) found incomplete recovery of intellectual functioning in a group of patients with severe TBI 1-year post-injury. Specifically, significant differences between estimated pre-morbid FSIQ and FSIQ at 1-year post-injury were found, despite significant improvements in FSIQ in the TBI group from 6-months to 1-year post-injury.

In summary, the neuropsychological consequences of TBI vary according to severity of injury. Neuropsychological deficits following uncomplicated MTBI are few

and tend to resolve in the vast majority of patients by 3-months post-injury. Research to date suggests that at least in the short-term following injury, patients with complicated MTBI suffer greater neuropsychological impairment compared to their uncomplicated MTBI counterparts. Further research is required to determine whether neuropsychological functioning after complicated MTBI more closely approximates that of patients with moderate TBI. In comparison, moderate and severe TBI leads to more pronounced and wide-spread neuropsychological impairments. Significant gains in cognitive performance occur within the first year following moderate to severe TBI; however, resolution of cognitive sequelae is far from complete and cognitive disability still commonly persists. Further recovery of neuropsychological functioning beyond the first year after moderate to severe TBI is variable, but modest at best.

Functional Outcome after TBI

Assessment of Functional Outcome Status

Formal neuropsychological assessment represents an essential component of the comprehensive TBI rehabilitation treatment regime. However, the assessment of functional status has similarly become a critical measure of outcome particularly given the movement towards providing a continuum of healthcare from injury through to community integration. As highlighted by Hall and colleagues, the functional assessment of patients within the scope of the rehabilitation setting may soon become the only means of justifying treatment effectiveness within the managed healthcare environment (Hall, Bushnik, Lakisic-Kazazic, Wright, & Cantagallo, 2001).

Functional outcome status refers to an individual's activity and participation levels within a broad range of everyday activities, routines, and social roles. According to

the original International Classification of Impairment, Disability, and Handicap [ICIDH] (WHO, 1980) *activities* are defined as physical and mental functions that are part of everyday routines and include learning and understanding, communication, movement, activities of daily living (ADLs), personal care, and interpersonal behaviours. Similarly, the ICIDH defines *participation* as the nature and extent of the individual's involvement in life situations, including the individual's role in the family and community. Currently, the most commonly used measures of functional status are based on the original ICIDH model (Hall et al., 2001).

A variety of functional outcome measures exist that assess both the short- and long-term status of persons with brain injury. Included among those most commonly used after TBI are the GOS, the Functional Independence Measure (FIM; Hamilton, Granger, Sherwin, Zielezny, & Tashman 1987), the Disability Rating Scale (DRS; Rappaport, Hall, Hopkins, Belleza, & Cope, 1982), and the Community Integration Questionnaire (CIQ; Wilier, Rosenthal, Kreutzer, Gordon, & Rempel, 1993).

The GOS is the most widely used measure of outcome after TBI (Clifton et al., 1993; Narayan et al., 2002). It is a brief descriptive ordinal scale consisting of five categories: good recovery (GR), moderate disability (MD), severe disability (SV), vegetative (V), and death (D; see Appendix E). In some clinical trials of head injury, the GOS is dichotomized to a favourable (good) outcome by combining GR and MD, and an unfavourable (poor) outcome by combining the remaining three categories (Narayan et al.). Alternatively, an extended version of the GOS is available which describes the upper range of outcome in more detail by dividing the first three categories in two for a total of eight categories (Wilson, Pettigrew, & Teasdale, 1998). Given its brevity and the

availability of more detailed instruments, the GOS is used primarily as a measure of early acute medical predictors of gross outcome after TBI (Hall et al., 2001). Likewise, critics contend that the outcome categories are too global and thus insensitive to the subtle changes and differences seen among brain-injured individuals (Clifton et al., 1993).

The FIM is an 18 item ordinal scale originally developed to resolve the lack of uniform measurement and data on inpatient medical rehabilitation by recording the severity of disability of rehabilitation inpatients. As the FIM was developed for use with all rehabilitation patients, it is not diagnosis (i.e., TBI) specific. Individual item scores on the FIM range from 1 to 7, with an item score of 7 categorized as "complete independence" and an item score of 1 as "total assist." Individuals with scores of 5 or less require that another person be present for supervision or assistance for that item.

Clinically appropriate validity and interrater reliability have been well established for the FIM (Hamilton, Laughlin, Granger, & Kayton, 1991). Similarly, Rasch analysis of the FIM defined two statistically and clinically unique domains: motor functions and cognitive functions (Linacre, Heinemann, Wright, Granger, & Hamilton, 1994; see Appendix F). Separate cognitive and motor domain FIM scores can be calculated, with a total cognitive score ranging from 5 to 35 and a total motor score ranging from 13 to 91. Higher scores reflect less disability.

The DRS, a TBI-specific outcome measure, was developed in a rehabilitation setting as a means of assessing the entire range of recovery from brain injury. As such, the DRS is recognized for its ability to monitor an individual's change in recovery from time of coma to reintegration into the community, thus providing consistency of the measurement baseline over time (Hall et al., 1996). The DRS uses a 30-point continuous

scale ranging from death (score of 30) to no disability (score of 0), and reflects changes in arousal and awareness, as well as changes in cognitive, functional, and psychosocial domains (see Appendix G). Compared to the GOS, the DRS has been shown to be more sensitive to clinical changes after TBI (Hall, Cope, & Rappaport, 1985). In addition to interrater and test-retest reliability, concurrent and predictive validity of the DRS have been well established (Eliason & Topp, 1984; Gouvier, Blanton, LaPorte, & Nepomuceno, 1987).

The CIQ was also developed specifically for use with individuals with TBI and is the most commonly used comprehensive measure of community integration following TBI (Dijkers, 1997). Factor analysis has supported the construct validity of the CIQ, suggesting the separation of the questionnaire's 15 items into three main dimensions: home integration (H), social integration (S), and productive activity (P; Sander et al., 1999). Likewise, sensitivity of the CIQ has been demonstrated by its ability to discriminate between a TBI and control sample, and among TBI survivors with three different levels of independent living (Wilier et al., 1993). The basis for scoring of the CIQ lies primarily in the frequency of performing roles or activities, with secondary weighting given to whether activities are done jointly with others. Scoring results in three dimension subtotal scores (i.e., H, S, and P) and a CIQ total score (ranging from 0-29), with higher scores indicating greater overall community integration (see Appendix H).

Functional Outcome after TBI

The majority of TBI outcome studies to date have described results in terms of the general TBI population as a whole, thus precluding a thorough understanding of the various domains of functional recovery across TBI of differing severity levels.

Nevertheless, compared to individuals with severe TBI, individuals sustaining mild or moderate TBI generally achieve favourable outcomes on functional measures post-injury (i.e., good recovery or moderate disability; van der Naalt, 2001). However, "good recovery" is not synonymous with "complete recovery" in these TBI patient populations as many individuals indeed have residual difficulties in their everyday functioning following mild to moderate TBI. As with the assessment of neuropsychological outcome following TBI, methodological limitations and discrepancies in the classification of TBI severity have served to hamper a clear understanding of functional outcome after mild to moderate TBI. In particular, a paucity of studies have investigated functional outcome after complicated MTBI, an area recognized by the WHO Task Force on MTBI in need of further investigation (Carroll et al., 2004). Of those studies conducted to date, the findings suggest that complicated MTBI results in poorer functional outcome than uncomplicated MTBI.

It is well established that functional outcome following uncomplicated MTBI is favourable. The vast majority of studies investigating functional status after MTBI have found good outcomes in both the short- and long-term (e.g., Gennarelli, Champion, Copes, & Sacco, 1994; Hsiang et al., 1997; Krause & Fife, 1985; Masson et al., 1996; Paniak, Toller-Lobe, Reynolds, Melnyk, & Nagy, 2000; Williams et al., 1990). According to the WHO Task Force on MTBI, studies that report significant disability after MTBI do not distinguish whether the disabilities are attributable to the MTBI, to pre-existing conditions, or to other injuries sustained in the original event (Carroll et al., 2004). Similarly, many studies do not differentiate between uncomplicated and complicated MTBI. For instance, in a recent prospective study of individuals age 14

years and older with MTBI, an astounding 47% of patients reportedly had a moderate or severe disability as measured by the GOSE at 1-year post-injury (Thornhill et al., 2000). Age over 40, pre-existing physical limitations, and a history of brain illness (e.g., stroke) were associated with poor outcome. However, limitations of the study included failing to take radiological imaging into account in determining severity of injury, as well as a high frequency of pre-existing and concurrent co-morbid health conditions in the sample that reduced the generalizability of the findings to other MTBI populations. In general, most methodologically sound studies suggest little or no residual functional disability in individuals after uncomplicated MTBI.

Conversely, the assessment of global outcome after complicated MTBI has yielded less favourable results. Using the GOS at 6-months post-injury, Williams et al. (1990) investigated outcome in patients with uncomplicated MTBI, complicated MTBI, and moderate TBI. The findings revealed that MTBI complicated by radiological evidence of parenchymal brain lesion or extradural hematoma resulted in worse outcome compared to uncomplicated MTBI. In addition, the 6-month GOS scores of the complicated MTBI patients were more similar to those of the moderate TBI patients.

In a similar study using the GOS, Hsiang et al. (1997) assessed outcome at 6-months post-injury in a large sample of patients after complicated and uncomplicated MTBI. The results revealed that within the conventional GCS classification range for MTBI, more severely injured patients had poorer outcome in comparison to patients with higher admission GCS scores and negative imaging. Specifically, 99.8% of patients with uncomplicated MTBI achieved a good outcome at 6-months post-injury. Conversely,

90% of patients with complicated MTBI achieved a good outcome, with the remaining 10% falling in the moderately to severely disabled range at 6-months post-injury.

The GOS has also been employed in the assessment of longer-term outcome in complicated MTBI and moderate TBI patients at 1-year post-injury (van der Naalt et al., 1999). Moderate disability was found in 12% of patients with complicated MTBI and in 29% of patients with moderate TBI. None of the patients in either group was classified as severely disabled at 1-year post-injury. Of further interest, no differences were found between the groups with respect to the number or severity of symptom complaints at 1-year post-injury.

In an investigation of patients with mild-to-moderate TBI, Novack and colleagues (2000) found significant gains in community integration and involvement in productive activities from 6- to 12-months post-injury on both the DRS and all three sub-dimension scales of the CIQ. Although the mild-to-moderate TBI group exhibited better functional outcome compared to a severe TBI group at both time periods, community integration was still far from complete. For example, over half of the mild-to-moderate group had not returned to driving at 1-year post-injury. Indeed, in a similar study of complicated MTBI and moderate TBI patients, outcome on the GOS was found to deteriorate from 12- to 24-months post-injury after an initial improvement in outcome from baseline to 1-year post-injury (Hellawell, Taylor, Pentland, 1999). To account for the unexpected decline in global outcome, it was hypothesized that a delay in the awareness of the full extent of the effects of the TBI may have occurred, such that over time there was an apparent deterioration in the individual's recovery. Additionally, it was suggested that a concomitant genuine deterioration in functional status may occur due to the introduction

or escalation of major life stressors such as loss of employment, marital breakdown, and the dissolution of one's social network as time from injury increases.

With respect to functional recovery following moderate-to-severe TBI, a dose-response relationship between severity of TBI and degree of integration appears to exist, with poorer integration evidenced by individuals with longer acute hospital stays, longer PTC, and greater functional disability upon discharge (Doig, Fleming, & Tooth, 2001). Fleming and Maas (1994) demonstrated that DRS scores on admission to inpatient rehabilitation had high predictive value for rehabilitation outcome. Specifically, patients with low DRS scores (i.e., more favourable) on admission achieved higher levels of functioning on the DRS at discharge. Notably, the only index of severity of injury contributing to discharge DRS scores was duration of PTC, with patients with prolonged PTC experiencing worse outcomes at discharge. Additionally, the presence of cognitive impairment was a predictor of discharge DRS scores, with more severe cognitive deficits related to higher levels of disability.

Functional outcome measures, including the CIQ and DRS, have also demonstrated improvements over time in terms of participation and community integration following post-acute TBI rehabilitation for moderate to severe TBI (Cicerone, Mott, Azulay, & Friel, 2004; Doig et al., 2001; Seale et al., 2002). However, community reintegration is highly variable in this heterogeneous population. For instance, in a cluster analysis of the CIQ subscales, Doig and colleagues (2001) found three distinct patterns of community integration in a large sample of moderate-to-severe TBI patients 2- to 5-years post-injury. Specifically, one group demonstrated a balanced pattern of community integration (e.g., high levels of independence in home, productive, and social activities);

a second group demonstrated active involvement in productive activities (e.g., engaged in work, school, or volunteer activities) but minimal involvement in home or social activities; and a final group was poorly integrated with low levels of participation in home, social, or productive activities. The poorly integrated group was characterized by more severe injury characteristics.

In summary, relatively few studies have investigated functional disability after complicated MTBI. Among those that have, findings from the GOS have revealed that patients with complicated MTBI fare worse than those with uncomplicated MTBI. Moreover, the findings suggest that functional outcome after complicated MTBI may more closely approximate that seen following moderate TBI. However, the GOS was designed as a broad observational rating scale, thus lacking sensitivity to detect subtle differences in functional status, particularly in higher functioning individuals. Likewise, the GOS does not directly address important ecologically relevant aspects of functional outcome such as type of disability, degree of independence with ADLs, level of community and social integration, or quality of life indices. In order to better understand the degree and extent of functional disability after complicated MTBI, future research must employ a wider range of outcome measures with this population of patients, as well as directly compare functional outcome between complicated MTBI and moderate TBI so as to better determine the natural course of recovery after complicated MTBI.

Relationship Between Neuropsychological Deficits and Functional Status Post-TBI

Cognitive impairment, as assessed by traditional neuropsychological measures, compromises functional status. Likewise, there is general agreement that cognitive and behavioural impairment represent two of the most significant areas of adjustment for

patients and families after TBI. However, the relationship between neuropsychological deficits and functional disability after TBI remains unclear. Moreover, most studies to date have focused on more severe TBI, resulting in a dearth of research examining the relationship between neuropsychological deficits and functional ability after TBI of lesser severity.

Within the context of neuropsychology, the concept of ecological validity has been defined as "the functional and predictive relationship between the patient's performance on a set of neuropsychological tests and the patient's behavior in a variety of real-world settings (e.g., at home, work, school, community)" (Sbordone, 1996, p. 16). Problematic is that traditional neuropsychological measures are frequently criticized for their lack of ability to adequately predict the daily functional capacity of individuals post-TBI (Clifton et al., 1993; Long, 1996). However, this lack of predictability is likely in part a reflection of the status of the research conducted to date, rather than confirmation that neuropsychological measures lack any ecological validity. For instance, in a recent review of the literature on neuropsychological assessment and employment outcome after TBI, Sherer et al. (2002) concluded that significant methodological limitations of studies conducted to date precluded a sound understanding of the relationship between neuropsychological test results and employment outcome. Similarly, the findings revealed that due to an overall lack of informative studies, additional investigation is necessary to determine the association between neuropsychological results and other important areas of outcome after TBI such as school success, managing one's finances, and living independently.

Lack of methodologically sound investigations aside, diversity of cognitive impairment after TBI represents a significant hindrance to predicting functional ability over time, even within TBI severity levels. For instance, despite the principal finding by Dikmen et al. (1995) of a dose-response relationship between TBI severity and neuropsychological outcome at 1-year post-injury, the authors highlighted variability of neuropsychological performance within head injury severity levels as a second key finding. That is, differential sparing or recovery of cognitive functioning was evident among individuals, especially as the severity of brain insult increased. As previously mentioned, Millis et al. (2001) likewise found that neuropsychological recovery continued for several years for a subset of individuals with moderate to severe TBI, whereas measurable impairments remained for other individuals. Thus, whereas cognitive recovery after TBI is clearly evident at the group level, regardless of severity of injury, remarkable differences between individuals with similar injury severities limits the generalizability of group findings.

Among those studies that have investigated performance on specific neuropsychological measures in relation to outcome post-TBI, results suggest an important role for the domain of executive functioning in recovery of functional ability. For instance, using the CIQ at 1-year post-TBI, Ross and colleagues found that in addition to age, information processing speed, memory, and complex attention were significantly related to levels of social integration (Ross, Millis, & Rosenthal, 1997). Similarly, Little and colleagues demonstrated a significant relationship between measures of processing speed, cognitive flexibility, and novel problem solving, and post-acute TBI rehabilitation DRS discharge scores (Little, Templer, Persel, & Ashley, 1996). Finally,

Hart et al. (2003) found that in addition to pre-injury status, measures of working memory and cognitive flexibility were significant predictors of supervision status at 1 - year post-TBI.

Interestingly, in a study investigating the predictive validity of measures of executive control and functional outcome in a population of mixed rehabilitation inpatients (i.e., TBI, orthopedic, and spinal cord injured patients), Hanks and colleagues found that tests tapping problem solving, abstraction, planning, cognitive flexibility, and working memory skills were strongly associated with rehabilitation outcome upon re-entry to the community as measured by the CIQ and the DRS (Hanks, Rapport, Millis & Deshpande, 1999). As highlighted by Hanks et al., the finding that measures of executive control predicted functional outcome beyond information regarding sensory and motor functioning offers support for the theoretical relationship between higher-order cognitive processes (i.e., executive functions) and real-world behaviours. That is, higher-order cognitive processes may be crucial for successful post-rehabilitation functioning once a patient's physical and/or sensory impairments have resolved, or intact higher-level cognitive functioning may afford the patient the ability to compensate for unresolved physical impairments.

Taken together, it appears that variability in cognitive and functional outcome after TBI has rendered many attempts to predict outcome less than satisfactory. This was highlighted in a review by Ponsford and colleagues (1995b) who reported that whereas significant correlations have been found between such variables as GCS scores, length of PTC, age at injury, presence of multiple trauma, and specific neuropsychological measures, and outcome on a range of functional measures, each variable alone predicted

less than 25% of the variance between groups. Given that functional outcome after TBI is influenced by a multitude of different factors, aside from cognitive impairment, a multivariate approach is clearly required to better predict functional status post-TBI. With respect to complicated MTBI, a better understanding of the natural history of recovery for this patient population is required and longitudinal investigations of specific functional and cognitive outcomes after complicated MTBI may best provide this necessary information.

Present Study

The alarming prevalence rate of TBI in combination with the widespread associated psychosocial and economic burden warrants further elucidation of differences in TBI outcome in order to optimize post-injury patient treatment and management. In particular, given that the traditional criteria for "mild" brain injury can no longer be considered a homogeneous classification range, treatment programs and assessment strategies currently used for MTBI in general may not be appropriate for patients with complicated MTBI. The present study seeks to contribute to the literature on recovery after complicated MTBI by determining if there is a differential relationship between patients with complicated MTBI and patients with moderate TBI on specific cognitive and functional measures at discharge from inpatient rehabilitation and at 1-year post-injury. The present study was divided into three parts in order to better address each research question of interest.

Study 1: Cognitive and Functional Performance at Baseline

Study 1 addressed whether a group of patients with complicated MTBI and another with moderate TBI differed cognitively and functionally upon discharge from

inpatient rehabilitation. Based on empirical evidence to date, it was expected that the complicated MTBI and moderate TBI groups would exhibit similar levels of impairment on measures of functional ability and cognitive performance at the time of discharge from inpatient rehabilitation.

Study 2: Cognitive and Functional Performance at 1-year Follow-up

Study 2 addressed whether cognitive and functional outcome at 1-year post-injury was comparable between these two TBI patient populations. Given that no study to date has investigated cognitive outcome among complicated MTBI patients beyond 6-months post-injury and those studies assessing longer term functional outcome have only relied on the GOS, level of impairment in the long-term within this TBI population remains unclear. Empirical findings have revealed significant recovery of cognitive and functional ability in patients with moderate TBI at 1-year post-injury, although recovery is not uniform across cognitive domains and variability in functional disability status remains. In general, a pattern of impairments in the areas of processing speed, higher-order cognitive processes, and learning and memory functioning are exhibited after moderate TBI at 1-year post-injury. Given the established dose-response relationship between severity of injury and outcome after TBI, it was expected that the complicated MTBI group would exhibit better overall outcomes with respect to both cognitive and functional status by 1-year post-injury, as compared to the moderate TBI patients. Thus, two hypotheses were posited: (a) the complicated MTBI group would exhibit cognitive and functional impairments at 1-year post-injury, but to a lesser degree compared to the moderate TBI group; or (b) by 1-year post-injury the complicated MTBI group would

return to pre-injury cognitive and functional levels, exhibiting neurocognitive performances and functional status within normal expectations.

Study 3: Descriptive Analysis of Group Outcomes

Finally, given the exploratory nature of the current research, Study 3 considered outcome after complicated MTBI from a broader clinical perspective by providing a descriptive analysis of functional outcome and level of neuropsychological impairment at baseline and at 1-year post-injury.

Method

The current investigations utilized retrospective data collected as part of the Southeastern Michigan Traumatic Brain Injury System (SEMTBIS) at the Wayne State University School of Medicine and the Rehabilitation Institute of Michigan. The SEMTBIS includes three acute care hospitals, all located in Detroit, and is a major referral base for local and remote hospitals wanting high-level rehabilitation for patients with brain injury. The SEMTBIS provides a continuum of care for persons suffering TBI, from the time of injury through to community reintegration. An important component of the SEMTBIS is its focus on research. It is one of 16 centers in the United States that forms the larger Traumatic Brain Injury Model System (TBIMS), and as such participates in clinical and systems analysis studies of the TBIMS by collecting and contributing data for submission to the TBIMS national data base.

The TBIMS program was created and funded by the National Institute on Disability and Rehabilitation Research in 1987 to demonstrate the benefits of a coordinated system of neurotrauma and rehabilitation care and to conduct innovative research on all aspects of care for persons who sustain traumatic brain injuries. All centers systematically collect data about each individual who meets criteria for inclusion in the TBI national database and send this information to the TBI National Data Center. Together, the TBIMS centers conduct research on many important aspects of TBI including applied technology, physical and rehabilitation medicine, therapeutic interventions, clinical trials, predictors of outcome and outcome measurement, and quality of life issues.

Participants

Data for the current study was provided from 229 participants in the SEMTBIS project. Inclusion criteria for the SEMTBIS project (and all TBIMS research projects in general) require that participants (1) be at least 16 years of age at the time of injury, (2) arrived at a TBIMS level I trauma center within 24 hours of injury, (3) received both acute care and inpatient rehabilitation in hospitals designated as TBIMS centers, and (4) provided informed consent to participate in the TBIMS project. Additionally, all participants must have sustained a medically documented TBI defined as injury to brain tissue caused by an external mechanical force as evidenced by LOC due to brain trauma, PTC, skull fracture, or by objective neurological findings that are reasonably attributable to TBI on a physical or mental status examination. Excluded were participants with lacerations and/or bruises of the scalp or forehead without other criteria listed above. Likewise, primary anoxic encephalopathy was excluded.

The complicated MTBI group was comprised of 102 participants, each with a documented brain lesion (i.e., via neuroimaging) and GCS score of 13 to 15. One hundred and twenty-seven participants with GCS scores ranging from 9 to 12 comprised the moderate TBI group. In order to increase the generalizability of the study sample, participants with a prior history of brain injury, substance use, or premorbid psychiatric or neurological disorder were not excluded. Information on participants' demographic background and injury-related medical history was coded from their medical records.

Procedures

As per the TBIMS protocol, participants were administered the neuropsychological test battery during their inpatient rehabilitation stay at one of the

TBIMS facilities (assessment results obtained during the time of the participants' inpatient rehabilitation will hereafter be referred to as "baseline" results). The neuropsychological battery was administered only after the participant had emerged from PTC. Emergence from PTC was defined by obtaining a score of 76 on the Galveston Orientation and Amnesia Test over the course of two consecutive days. A participant returned for a follow-up neuropsychological evaluation within 2-months of the 1-year anniversary of his or her discharge from inpatient rehabilitation.

Measures of functional disability were also completed twice, once at the time of the participant's discharge from inpatient rehabilitation and again within 2-months of the 1-year anniversary of his or her injury. Specifically, multidisciplinary hospital TBI team members ensured completion of the measures at the time of inpatient discharge, and SEMTBIS research staff assisted with the completion of the measures at the 1-year follow-up via an interview with the participant and/or significant caregiver. Follow-up interviews were conducted in person or by telephone.

The neuropsychological tests and functional assessment measures were administered and scored according to standardized test instructions by experienced neuropsychologists and supervised technicians. Neuropsychological and functional status data used in the current study were collected from 1989 through 2002, with the dates of injury for participants ranging from 1989 to 2001.

Measures

The SEMTBIS project collects data on numerous neuropsychological measures. In order to justify statistical methods employed with the current sample size, neuropsychological measures were selected *a priori*, based on their utility in the

assessment of TBI. The neuropsychological test battery included standard measures used to assess a broad range of cognitive abilities including attention, visuospatial integration, memory for verbal information, working memory, information processing speed, problem solving, abstract reasoning, and cognitive flexibility.

The neurocognitive assessment measures of interest in the current study included the Block Design Test (raw score; Wechsler, 1981), Controlled Oral Word Association Test (CO WAT: total number of words generated; Benton & Hamsher, 1989), Digits Backward (number of trials correct; Wechsler, 1987), Logical Memory I (LM-I: number of story elements correctly recalled immediately following presentation) and Logical Memory II (LM-II: number of story elements recalled after 30-minute delay) subtests of the Wechsler Memory Scale - Revised (Wechsler, 1987), Rey Auditory Verbal Learning Test (RAVLT: sum of total number of words recalled across Trials 1-5; Rey, 1958), Symbol Digit Modalities Test - Oral (SDMT-Oral: total number correct; Smith, 1982), Trail Making Test (Trails A and Trails B: TMT-A and TMT-B: time to complete in seconds; Army Individual Test Battery, 1944), and the Wisconsin Card Sorting Test (WCST: number of perseverative responses; Grant & Berg, 1948). A description of each neuropsychological measure is provided in Appendix I.

The functional outcome measures of interest in the current study included the FIM, DRS, and the CIQ. Separate ratings for the FIM motor and cognitive domain items were used in order to assess domain-specific scores. Notably, completion of the CIQ occurred only at the time of the 1-year follow-up. Each measure was previously described above, and appendices F through H provide detailed summaries of each measure.

Statistical Analyses

Independent t-tests were used to assess TBI group differences with respect to demographic (e.g., age, education) and injury severity variables (e.g., duration of LOC and PTC). In the instance of nominal data variables (e.g., gender, ethnicity), chi-square analyses were employed.

As is typical in prospective studies of clinical factors, missing data and partially observed predictors are commonplace. In the current study, participants having data available for both time periods varied across measures (see Table 1). To avoid the inefficiency and inherent bias of using a complete case analysis statistical approach which necessitates dropping participants with any missing observations, the current study employed the statistical modeling technique of multiple imputation (Rubins, 1987) using R statistical software. The strength of multiple imputation modeling is the ability to estimate missing data by generating multiple complete datasets based on plausible values for missing observations that reflect uncertainty about the model. These values are then used to fill in (i.e., impute) the missing data. The results of each newly generated dataset are combined so that statistical analyses conducted on the imputed dataset take into account the uncertainty of the imputation. Thus, the multiply imputed data sets can be analyzed using standard procedures for complete data. Multiple imputation is considered a powerful method for handling missing data and is advantageous for use when applied to longitudinal data (Horton & Kleinman, 2007; Tabachnick & Fidell, 2001). Appendix J illustrates the three principal steps of multiple imputation modeling.

Table 1
 Frequency of available participant data at baseline and 1-year post-injury

Variable	Baseline		1-Year Post-iniurv	
	cMTBI	Moderate TBI	cMTBI	Moderate TBI
	raw	raw	raw	raw
Age	102(100%)	127 (100%)	102 (100%)	127 (100%)
PTC	89 (87%)	111 (87%)	89 (87%)	111 (87%)
LOC	96 (94%)	124 (98%)	96 (94%)	124(98%)
GCS	102 (100%)	127(100%)	102 (100%)	127(100%)
DRS	100 (98%)	126 (99%)	66 (65%)	73 (58%)
FIM Cognitive	98 (96%)	126 (99%)	62 (61%)	70 (55%)
FIM Motor	96 (94%)	121 (95%)	62(61%)	66 (52%)
CIQ			59 (58%)	66 (52%)
LMI	57 (56%)	68 (54%)	46 (45%)	49 (39%)
LMII	56 (55%)	68 (54%)	45 (44%)	49 (39%)
Digits Backward	54 (53%)	73 (58%)	45 (44%)	49 (39%)
COWAT	56 (55%)	70 (55%)	44 (43%)	48 (38%)
RAVLT	50 (49%)	67 (53%)	42 (44%)	47 (37%)
SDMT-0	47 (46%)	55 (43%)	39 (38%)	41 (32%)
TMT-A	56 (55%)	69(43%)	38 (37%)	42 (33%)
TMT-B	45 (44%)	65(51%)	38 (37%)	39(31%)
Block Design	51 (50%)	54 (43%)	38 (37%)	39(31%)
WCST	36 (35%)	40 (32%)	31 (30%)	26 (21%)

cMTBI: complicated mild traumatic brain injury; TBI: traumatic brain injury; PTC: Post-traumatic confusion; LOC: Loss of consciousness; GCS: Glasgow Coma Scale; DRS: Disability Rating Scale; FIM: Functional Independence Measure; CIQ: Community Integration Questionnaire; LM: Logical Memory; COWAT: Controlled Oral Word Association Test; RAVLT: Rey Auditory Verbal Learning Test; SDMT-O: Symbol Digit Modalities Test-Oral; TMT: Trail Making Test; WCST: Wisconsin Card Sorting Test.

Binary logistic regression analyses using the imputed data model were conducted to determine how participants with complicated MTBI differed from those of moderate TBI status on specific measures of functional disability and neuropsychological performance at discharge from inpatient rehabilitation (Study 1) and at 1-year post-injury (Study 2). Functional disability and neuropsychological performance were considered using separate analyses corresponding to the two time periods of interest following injury.

Investigation of the clinical significance of each group's performance over time was conducted in Study 3 via a descriptive analysis of the degree of functional and neuropsychological impairment at baseline and 1 year post-injury. By comparing each group's mean score on the neuropsychological measures to each measure's demographically appropriate normative data, a level of impairment for each neuropsychological variable was determined. To do so, a prototypical patient was created based on the mean demographic characteristics of each group (i.e., a 49-year-old man with 12 years of education in the complicated MTBI group; a 36-year-old man with 12 years of education in the moderate TBI group). The qualitative descriptors for levels of impairment corresponded to those suggested by Heaton and colleagues (Heaton, Miller, Taylor, & Grant, 1991). Appendix K outlines the impairment rating scheme used in the current study.

Results

Group Demographics and Injury Severity Characteristics

Independent t-tests and chi-square analyses revealed no statistically significant differences ($p > .05$) between the complicated MTBI and moderate TBI groups on level of education ($p > .05$, Fisher's Exact Test), gender ($p > .05$, Fisher's Exact Test), ethnicity ($\chi^2(3, N = 229) = 2.56$), or marital status ($\chi^2(5, N = 229) = 5.19$) at the time of injury. Conversely, the complicated MTBI group was significantly older than the moderate TBI group ($F(2,227) = 6.18, p < .001$, Cohen's $d = 0.41$; see Table 2).

Table 2

Demographic statistics for complicated MTBI and moderate TBI groups at time of injury

Variable	cMTBI	Moderate TBI
Age*	Mean: 48.58 (SD: 16.42)	Mean: 36.24 (SD: 13.80)
Gender	81% Male	78% Male
Education	40.6% < High School or GED 59.4% > High School	52.8% < High School or GED 47.2% > High School
Ethnicity	74% Black 23% White 3% Other	70% Black 28% White 2% Other
Marital Status	49% Single 15% Married 23% Divorced 6% Separated 7% Widowed	58% Single 13% Married 13% Divorced 7% Separated 8% Widowed

cMTBI: complicated mild traumatic brain injury; TBI: traumatic brain injury

*/ $p < .001$

Comparison of injury severity characteristics revealed statistically significant differences between the groups, all in the expected direction of greater injury severity in the moderate TBI group ($p < .01$). As illustrated in Table 3, the moderate TBI group endured a longer duration of LOC and PTC compared to the complicated MTBI group ($F(2,18) = -3.66; F(1,198) = -4.20$, respectively). Similarly, the moderate TBI group spent

more days hospitalized in both acute care and rehabilitation settings following injury ($t(227) = -3.36$; $r(227) = -2.76$, respectively). Given that participants' highest GCS scores were used as the criteria for TBI group classification, the statistics pertaining to group GCS scores in Table 2 are provided for descriptive purposes only. Indeed, the moderate TBI group had a significantly lower mean GCS score ($t(225) = 34.72$). Effect sizes were calculated as the difference in means divided by the pooled standard deviation (Glass & Hopkins, 1996). Excluding GCS score, effect sizes for injury severity variables were all small.

Table 3
Injury severity statistics for complicated MTBI and moderate TBI groups

Variable	cMTBI Mean (<i>SD</i>)	Moderate TBI Mean QSD)	<i>p</i>	Cohen's <i>d</i>
Highest GCS score	14.44 (.711)	10.55 (.982)	.000*	2.30
Duration of LOC ^a (days)	3.68(5.50)	6.79(7.10)	.000*	0.25
Duration of PTC (days)	25.48(22.66)	39.42(23.87)	.000*	0.30
LOS Acute Care (days)	14.21(14.24)	21.27(16.95)	.001*	0.23
LOS Rehabilitation (days)	24.05(13.97)	29.13(13.78)	.006*	0.18

cMTBI: complicated mild traumatic brain injury; TBI: traumatic brain injury; LOC: loss of consciousness; LOS: length of stay; GCS: Glasgow Coma Scale.

* $p < .05$

^aLOC calculated as number of days until the patient obtained a GCS motor response score of 6.

No differences existed between the groups with respect to history of prior TBI ($\chi^2(1, N = 220) = .051$; $p > .05$; $\phi = -.015$), with 11% of complicated MTBI and 10% of moderate TBI having reported a history of TBI. Participants in both groups sustained their current TBIs primarily from motor vehicle collisions, gunshot wounds, blunt assault, falls, and being struck by a vehicle as a pedestrian, with a small percentage sustaining injuries by various other means (e.g., bicycle accidents, sports, other violence). Table 4

lists causes of traumatic brain injury for each group. Notably, the most common cause of brain injury among participants in each group was blunt assault.

Table 4

Cause of traumatic brain injury

Cause	cMTBI (% of participants)	Moderate TBI (% of participants)
Blunt Assault	43	32
Motor Vehicle Collision	15	25
Fall	23	12
Pedestrian	15	13
Gunshot	3	12
Other	2	6

cMTBI: complicated mild traumatic brain injury; TBI: traumatic brain injury

Study 1: Cognitive and Functional Performance at Baseline

A binary logistic regression using as covariates age, length of PTC, education, and scores on the DRS, FIM motor domain, and FIM cognitive domain at the time of discharge from inpatient rehabilitation found only age and length of PTC to be significant predictors ($p < .01$), indicating that increased age and shorter PTC were associated with the complicated MTBI group. Thus, measures of functional ability failed to differentiate the groups at baseline.

In terms of cognitive performance, results of a binary logistic regression analysis used to determine group differences in neuropsychological performances revealed that in addition to age and duration of PTC ($p < .01$), performance on only two measures differentiated the complicated MTBI and moderate TBI groups at baseline. Poorer performance on the Block Design test was predictive of the moderate TBI group, whereas poorer performance on the WCST as indicated by more perseverative responses was, unexpectedly, predictive of the complicated MTBI group ($p < .05$) at baseline. However,

the associated odds ratios for these two significant predictor variables were relatively small, at 1.05 and 1.01, respectively.

Study 2: Cognitive and Functional Performance at 1-year Follow-up

Both the complicated MTBI and moderate TBI groups completed the follow-up evaluation approximately 1-year after discharge from inpatient rehabilitation (mean days = 334.26, $SD = 45.07$; mean days = 333.68, $SD = 36.00$, respectively). There was no significant difference in time to follow-up between the groups ($\chi^2(131) = .086$; $p > .05$; Cohen's $d = .01$).

Results of the binary logistic regression conducted on 1-year post-injury data using as covariates age, education, and duration of PTC as well as scores on the DRS, FIM motor and cognitive domains, and the CIQ home integration and productivity subscales, revealed again age and length of PTC as the only two significant predictors ($p < .05$). Thus, as with baseline abilities, no differences on measures of functional ability were found between the groups at 1-year follow-up.

With respect to group differences in neuropsychological performance at 1-year post-injury, results of the binary logistic regression analysis revealed that in addition to age and duration of PTC ($p < .05$), scores on three neuropsychological measures differentiated the groups. As with baseline performance, increased perseverative responses on the WCST was again predictive of the complicated MTBI group ($p < .05$). Also unexpected was the finding that fewer words generated on the COWAT was predictive of the complicated MTBI group at follow-up. However, the odds of the complicated MTBI group committing more perseverative responses on the WCST at 1-year post-injury were less than 2% and the odds of this group generating fewer words on

the COWAT compared to the moderate TBI group were also relatively small at 4%.

Finally, at the time of the 1-year follow-up, better performance on the SDMT-Oral was associated with the complicated MTBI group ($p < .05$).

Descriptive statistics for measures of functional ability and neuropsychological performance at baseline and at 1-year post-injury are provided in Table 5. Table 6 lists the odds ratios for the statistically significant neuropsychological predictor variables at both time periods.

Table 5
Descriptive statistics for functional and neuropsychological performance at baseline and 1-year post-injury

Variable	Baseline		1-Year Post-iniurv	
	cMTBI	Moderate TBI	cMTBI	Moderate TBI
	Mean (<i>SD</i>) 95% CI	Mean (<i>SD</i>) 95% CI	Mean (<i>SD</i>) 95% CI	Mean (<i>SD</i>) 95% CI
DRS	5.92(3.16) 5.29-6.54	6.26 (3.00) 5.73-6.69	2.94(2.61) 2.30-3.58	3.04(2.60) 2.43-3.65
FIM Cognitive	23.64(6.01) 22.44-24.85	23.50 (5.93) 22.49-24.51	30.79 (4.34) 29.69-31.89	30.50 (4.49) 29.43-31.57
FIM Motor	74.51 (16.41) 71.19-77.84	74.65 (16.65) 71..66-77.65	86.02(13.54) 82.58-89.46	86.08(13.67) 82.72-89.44
CIQ (total score)			12.64 (4.63) 11.44-13.85	14.12(5.91) 12.67-15.57
LMI (number correct)	19.14(7.04) 17.27-21.01	15.37(7.50) 13.55-17.18	18.43(8.73) 15.84-21.03	16.37(7.97) 14.08-18.66
LMII (number correct)	12.48 (7.39) 10.50-14.46	8.56 (7.26) 6.80-10.32	13.16(8.10) 10.72-15.59	10.43 (8.36) 8.03-12.83
Digits Backward (trials correct)	4.30(1.77) 3.81-4.78	4.52 (2.30) 3.98-5.06	5.04 (2.09) 4.42-5.67	5.69 (2.54) 4.97-6.42
COWAT (number correct)	25.79 (7.95) 23.66-27.91	24.99(9.16) 22.80-27.17	27.84 (9.98) 24.81-30.88	29.10(11.29) 25.83-32.38
RAVLT (Sum of trials I-V)	35.74(11.85) 32.37-39.11	31.60(9.53) 29.27-33.92	35.52(12.74) 31.55-39.49	32.00 (12.80) 28.24-35.76
SDMT-0 (number correct)	31.21 (12.70) 27.48-34.94	30.56 (14.08) 26.76-34.37	38.77(15.46) 33.76-43.78	35.73(13.61) 31.44-40.03
TMT-A (time in seconds)	72.57 (49.20) 59.40-85.75	63.30(39.15) 53.90-72.71	64.11 (50.25) 47.59-80.62	49.40(23.36) 42.12-56.69
TMT-B (time in seconds)	167.47(87.45) 141.91-193.74	169.11 (81.64) 148.88-189.34	154.87(48.52) 125.77-183.96	134.92(72.91) 111.29-158.56
Block Design (raw score)	16.94(9.46) 14.28-19.60	16.33 (8.08) 14.13-18.54	19.89(11.53) 16.10-23.68	22.46(11.16) 18.84-26.08
WCST (perseverative responses)	44.42 (36.54) 32.05-56.78	30.00 (26.73) 21.45-38.55	40.45 (33.70) 28.09-52.81	29.77(19.83) 21.76-37.78

cMTBI: complicated mild traumatic brain injury; TBI: traumatic brain injury; CI: confidence interval; DRS: Disability Rating Scale; FIM: Functional Independence Measure; CIQ: Community Integration Questionnaire; LM: Logical Memory; COWAT: Controlled Oral Word Association Test; RAVLT: Rey Auditory Verbal Learning Test; SDMT-O: Symbol Digit Modalities Test-Oral; TMT: Trail Making Test; WCST: Wisconsin Card Sorting Test.

Table 6
Significant neuropsychological predictor variables at baseline and 1-year post-injury

Variable	<u>Baseline</u> Odds Ratio	<u>1-Year Post-injury</u> Odds Ratio
WCST	1.01*	1.02*
Block Design	1.05*	
COWAT	---	0.96*
SDMT-Oral	-->--	<u>1.07*</u>

CI: confidence interval; WCST: Wisconsin Card Sorting Test; COWAT: Controlled Oral Word Associates Test; SDMT: Symbol Digit Modalities Test.

* Significantly differentiated the complicated MTBI group from the moderate TBI group ($p < M$).

Notably, the above results for Studies 1 and 2 were based on the classification of TBI groups according to patients' highest GCS scores. To control for the possibility that patients' highest GCS scores did not accurately represent the severity of TBI ensued (e.g., a patient's GCS score deteriorated to a level indicative of a more severe injury), the statistical analyses described above were also conducted on groups classified using GCS scores at admission to the ED (complicated MTBI $n = 80$; moderate TBI $n = 76$). Logistic regression analyses again revealed no between-group differences on functional outcome measures at rehabilitation discharge or at 1-year post-injury. Likewise, regression analyses using neuropsychological performances as covariates yielded similar results to those obtained based on highest GCS scores, with the exception that more perseverative responses on the Wisconsin Card Sorting Test at rehabilitation discharge and less words generated on the Controlled Oral Words Association Test at 1 year follow-up were no longer associated with the complicated MTBI group.

Study 3: Descriptive Analysis of Group Outcomes

To consider the significance of the TBI groups' neuropsychological performances from a broader clinical perspective, a descriptive analysis of cognitive impairment was

conducted. Table 7 details levels of impairment on the neuropsychological measures based on normative data for a prototypical patient within each TBI group (i.e., a 49-year-old man with 12 years of education in the complicated MTBI group; a 36-year-old man with 12 years of education in the moderate TBI group). Qualitative examination of impairment levels at both rehabilitation discharge and 1-year post-injury revealed more severely impaired information processing speed (e.g., SDMT-Oral) and verbal learning (e.g., LM I & II, RAVLT) in the moderate TBI group at both time periods. Based on level of impairment, Block Design performance no longer differentiated the groups at baseline, with both groups performing in the mildly impaired range. Similarly, despite increased odds of poorer performance by the complicated MTBI group at 1-year post-injury on the COWAT, both groups exhibited within normal limits performances on this task. The complicated MTBI group's performance on the WCST at rehabilitation discharge was indeed marginally more impaired compared to the moderate TBI group (i.e., moderately impaired versus mildly to moderately impaired), although no differences in level of impairment on this task existed by 1-year following injury. Despite overall improvement across cognitive domains within the complicated MTBI group, some degree of impairment remained at 1-year post-injury on those tasks identified as impaired soon after injury.

Table 7
 Impairment ratings on neuropsychological measures at baseline and 1-year post-injury

Measure	Baseline		1-Year Post-injury	
	cMTBI	Moderate TBI	cMTBI	Moderate TBI
LMI (number correct)	mild	moderate	mild	moderate
LMII (number correct)	average	mild	average	mild
Digits Backward (trials correct)	average	average	average	average
COWAT (number correct)	average	mild	average	average
RAVLT (Sum of trials I-V)	mild	mild-moderate	mild	mild-moderate
SDMT-0 (number correct)	moderate	moderate-severe	mild	moderate
TMT-A (time in seconds)	moderate	moderate	mild-moderate	mild
TMT-B (time in seconds)	mild	mild-moderate	mild	mild
Block Design (raw score)	mild	mild	mild	mild
WCST (perseverative responses)	moderate	mild-moderate	mild-moderate	mild-moderate

cMTBI: complicated mild traumatic brain injury; TBI: traumatic brain injury; LM: Logical Memory; COWAT: Controlled Oral Word Association Test; RAVLT: Rey Auditory Verbal Learning Test; SDMT-O: Symbol Digit Modalities Test-Oral; TMT: Trail Making Test; WCST: Wisconsin Card Sorting Test.

Finally, to gain a better appreciation of functional outcome and level independence after complicated MTBI, a descriptive analysis of functional measures was conducted. As the FIM considers a score of 6 or 7 for any of the motor and cognitive domain items as "independence" in performing that function, summing across domain items results in a total score > 78 on the FIM motor domain (i.e., 13 motor function items multiplied by 6) and a total score > 30 on the FIM cognitive domain (i.e., 5 cognitive function items multiplied by 6) as equivalent to full domain independence. Using these

cut-off scores, at the time of rehabilitation discharge 51% of patients in the complicated MTBI group were considered independent on the FIM motor domain, whereas only 15% of this group was independent on the FIM cognitive domain. By 1-year post-injury, independence on the FIM motor and cognitive domains improved to 95% and 71%, respectively, indicating near resolution of physical disability but continued difficulty in terms of everyday comprehension, expression, social interaction, problem solving, and memory in nearly one-third of the group. Functional outcome after complicated MTBI using the broader measures of employability status and community integration were also explored. Using the dichotomy of employable versus unemployable from the DRS, only 7% of patients in the complicated MTBI group were considered employable at discharge from rehabilitation versus 69% at 1-year following injury. Unexpectedly, degree of community integration within the complicated MTBI group at 1-year post-injury, as reflected by the CIQ total score, was comparable to CIQ scores obtained in patients with moderate and severe TBI (Novack et al., 2000; Sander et al., 1999).

Notably, no differences were found between the complicated MTBI and moderate TBI groups in terms of FIM motor and cognitive domain independence or employability status at either time period (Fisher's Exact Tests/? > .05) and an independent t-test showed no between-group differences on the CIQ total score ($t(2) = -1.57, p > .05$).

Discussion

Results of the current study supported the hypothesis of similar levels of cognitive and functional outcome between complicated MTBI and moderate TBI patients soon after injury. Unexpectedly, the finding of equivalent functional dependence and similar levels of cognitive impairment at 1-year post injury did not support the hypothesis of better outcome following complicated MTBI in the longer term. Overall, sufficient parallels in outcome after complicated MTBI and moderate TBI were found to indicate that when classifying severity of TBI based on GCS scores, consideration of a moderate injury designation should be given to persons with an intracranial bleed and a GCS score between 13 and 15.

Previous studies have demonstrated better neuropsychological performance after uncomplicated MTBI compared to MTBI complicated by a brain lesion despite similar GCS scores and durations of LOC and PTC between these two TBI populations. For instance, Borgaro and colleagues (2003) found that patients with complicated MTBI performed significantly worse than uninjured control participants on all cognitive measures of the BNI Screen for Higher Cerebral Functions at 1-month post-injury, whereas GCS score-matched uncomplicated MTBI patients' performances were comparable to uninjured controls. Likewise, Williams and colleagues (1990) found similar impairment levels within 3-months post-injury between complicated MTBI and moderate TBI patients on measures of information processing, memory, and word generation as compared to unimpaired performances in patients with uncomplicated MTBI whose duration of LOC and PTC were equivalent to those of the complicated MTBI group. The current study extends previous findings by demonstrating that

neuropsychological performances on only two measures at rehabilitation discharge and three measures at 1-year post-injury statistically differentiated the complicated MTBI group from the moderate TBI group. Moreover, qualitative examination of levels of impairment based on normative data effectively nullified any group differences on these identified neuropsychological measures.

Further consideration of levels of cognitive impairment across groups revealed more impaired information processing speed and learning and memory functioning in the moderate TBI group at both time periods of interest. This finding is consistent with prior research demonstrating that existing residual cognitive deficits after TBI are most commonly exhibited as slowed processing speed and compromised learning and memory (Dikmen et al., 1995; Levin et al., 1990). That the moderate group exhibited more impaired performances compared to the complicated MTBI in these cognitive domains even shortly after injury suggests appreciable differences in the vulnerability of the associated neural systems between these two TBI populations. Furthermore, that complete resolution of cognitive functioning to unimpaired levels did not occur within the complicated MTBI group by 1-year post-injury provides additional evidence that despite similar durations of LOC and PTC, neuropsychological outcome after complicated MTBI does indeed differ from patients with uncomplicated MTBI whose neuropsychological status is expected to return to premorbid levels by 3-months following injury (Kashluba et al., 2004; Levin et al., 1987; Ponsford et al., 2000).

In terms of functional status, the current study found no between-group differences at either time period of interest. Previous studies using the Glasgow Outcome Scale found that outcome after complicated MTBI was poorer in comparison to

uncomplicated MTBI, such that outcome scores after complicated MTBI more closely approximated those of patients with moderate TBI (Hsiang et al., 1997; van der Naalt et al., 1999; Williams et al., 1990). By using more sensitive measures of TBI outcome and assessing a broader range of functional abilities, the current results extend previous findings by demonstrating equivalent outcomes in terms of levels of physical (i.e., FIM motor domain) and cognitive (i.e., FIM cognitive domain) independence, employability (i.e., DRS), and degree of community integration (i.e., CIQ) between complicated MTBI and moderate TBI patients. As with neuropsychological outcome, recovery of functional status was far from complete by 1-year post-injury, thus providing further evidence of disparate outcomes after complicated MTBI vis-a-vis uncomplicated MTBI. For instance, within the complicated MTBI group total scores on the DRS corresponded to the partially impaired range, 29% of patients remained in the dependent range on the FIM cognitive domain, nearly one third of the group remained unemployable, and level of community integration at 1-year post-injury was similar to that of patients with moderate to severe TBI (Levin et al., 1990; Novack et al., 2000).

Differences in level of cognitive impairment with respect to information processing speed and learning and memory functioning across time between the complicated MTBI and moderate TBI groups in the current study did not translate into discrepancies in the groups' ability to participate within a broad range of everyday physical and mental activities, routines, and social roles as assessed by measures of functional ability. Equally deficient functional recovery at 1-year post-injury in both TBI groups, despite more impaired cognitive performance on some tasks by the moderate TBI patients, is likely partially explained by the complexity of cognitive processes required to

adequately engage in a functional activity, such that impairments within a specific cognitive domain do not directly correspond to specific functional disability. Studies to date have demonstrated an important role for the cognitive domain of executive functioning in the recovery of functional ability post-TBI. For example, using the CIQ at 1-year post-TBI, Ross and colleagues (1997) found that age, information processing speed, memory, and complex attention were related to levels of social integration. Little et al. (1996) demonstrated a significant relationship between processing speed, cognitive flexibility, and novel problem solving, and post-acute TBI rehabilitation discharge scores on the DRS. Similarly, in a mixed sample of rehabilitation inpatients, Hanks and colleagues (1999) found that measures of executive control predicted rehabilitation outcome upon community re-entry beyond information pertaining to sensory and motor dysfunction.

In addition to cognitive performance, the prediction of functional outcome post-TBI is complicated by a wide array of other moderating variables. To further our understanding of functional outcome and enhance our ability to better predict functional ability after TBI, additional research exploring the interaction between intrinsic (e.g., premorbid personality, mood, pain) and extrinsic (e.g., vocational history, family, social support) factors and cognitive status post-TBI is required. That is, it is important to consider the level at which a patient was functioning premorbidly when assessing his or her recovery of functional ability post-TBI. Although level of premorbid functioning is difficult to ascertain, research to date suggests that a patient's level of premorbid functioning across many domains plays a key role in the degree of his or her post-injury recovery and functional level. For example, in a recent study investigating the role of risk

factors associated with persisting symptom complaints after MTBI, Kashluba and colleagues found higher rates of premorbid mental health-related factors in a group of patients reporting more severe symptoms 3-months post-MTBI compared to a group reporting mild or negligible symptoms at the same time period post-MTBI (Kashluba, Paniak, & Casey, 2008). Specifically, the persistent symptom complaint group reported more pre-injury treatment for psychological problems, more premorbid analgesic, psychological, or neurological pharmacological treatment, and more pre-injury life stressors. Similarly, in an earlier study examining factors affecting outcome after TBI, Novack and colleagues found that better premorbid functioning had a positive influence on functional skills, cognitive status, and overall outcome (Novack, Bush, Meythaler, & Canupp, 2001). Premorbid factors considered in the study included age, level of education, and employment at the time of injury, as well as drug, alcohol, mental health, and involvement in criminal activities. Notably, Novack et al. found that being employed at the time of injury was especially important in terms of better functional outcome post-TBI.

Applying such considerations to the current study, it is noteworthy that both the complicated TBI and moderate TBI groups had relatively high rates of unemployment at the time of injury (i.e., 35% of complicated MTBI and 47% of moderate TBI patients were unemployed and looking for work). Similarly, 44% of the complicated MTBI group and 28% of the moderate TBI group had been arrested at least once prior to sustaining their TBI. Although it is difficult to determine the effect of these premorbid factors on the current study's group outcomes, it is likely that level of premorbid functioning contributed to the degree of functional outcome at 1-year post-injury. With the view of

allowing for better comparisons of results across studies, greater consideration of the role of premorbid functioning should be given in future investigations of outcome after TBI, regardless of the severity of injury.

Results of the current study revealed sufficient parallels in outcome after complicated MTBI and moderate TBI to indicate that the incorporation of a new subclassification of TBI is not warranted and that patients with GCS scores of 13 to 15 and evidence of an intracranial bleed should be classified as moderate TBI. Consequently, the focus of treatment and rehabilitation following complicated MTBI should differ from that used after uncomplicated MTBI. For instance, standard and sufficient treatment following uncomplicated MTBI includes observation in the emergency room with discharge once the patient is fully oriented, psychoeducation of both the common symptom complaints after MTBI (e.g., headache, fatigue, irritability, forgetfulness) and the expected 3-month time course for symptom resolution, reassurance of an expected good outcome, and encouragement to become active as soon as possible after the injury (e.g., Borg et al., 2004; Ponsford et al., 2002). Given the risk of poorer outcome after complicated MTBI, a more extensive treatment regime is warranted for this group of patients. Thus, expectations regarding the cognitive and functional limitations after complicated MTBI should be conveyed to patients, family members, and employers so as to promote optimal accommodations and assistance with transitioning back to the larger community as recovery progresses. Behavioral interventions pertaining to supervision, decision-making, and the work environment, as well as issues related to mood and adjustment should be addressed accordingly with this TBI population. Similarly, longer-term follow-up should be provided, including neuropsychological

assessment, to determine the effects of residual cognitive deficits on work, social integration, and functional independence.

Furthermore, the current findings highlight the limitations of solely relying on GCS scores in the classification of TBI severity given that some persons falling within the conventional "mild" GCS range of injury severity sustain intracranial lesions that place them at risk for poorer outcome. Indeed, studies have shown that patient presentations characterized by GCS scores of 15 and a brief LOC and PTC do not preclude the existence of intracranial abnormalities (Jeret et al., 1993; Vollmer & Dacey, 1991). Greater consideration of other injury severity factors such as duration of LOC, length of PTC, and time to follow commands should be considered in the classification of TBI severity. Support for the use of duration of PTC has emerged with studies demonstrating its predictive value in determining outcome after TBI. For instance, van der Naalt and colleagues (1999) found that injury outcome after mild and moderate TBI, as measured by functional outcome scores and return to work, was better determined by duration of PTC, whereas GCS scores failed to predict functional outcome or return to work. Regardless of GCS score, patients with longer durations of PTC had poorer overall outcomes. As highlighted by opponents of classifying TBI severity solely on GCS scores, a particular strength of using duration of PTC relates to its increased reliability as a continuous prospective measure of impaired cerebral functioning, rather than a single measure as is represented by a GCS score. The accuracy of GCS scores is further compromised by the early medical management often required by patients after TBI (e.g., intubation or the administration of sedative medications), and by patient-specific factors

such as intoxication at the time of injury (Sherer, Struchen, Yablon, Wang, & Nick, in press; Stocchetti et al., 2004; Zafonte et al., 1996).

Within the widely used definition of MTBI published by the American Congress of Rehabilitation Medicine (1993), it is stated that a designation of MTBI includes an initial GCS score of 13-15 and duration of PTC and LOC not exceeding 24 hours or 30 minutes, respectively. Problematic is that a patient's GCS score can fall within these parameters, but their duration of PTC and LOC exceed the definition's timeframe. By way of illustration, 91% of the current study's complicated MTBI group had a duration of PTC greater than 24 hours and 66% had a LOC longer than 30 minutes. Using all three criteria together (i.e., GCS score, PTC, and LOC), only 6% of the current study's complicated MTBI group would fall within the American Congress of Rehabilitation Medicine's "mild" range for traumatic brain injury severity. Similarly, in a recent study comparing different indices of TBI severity, Sherer and colleagues (in press) found that whereas approximately one third of their study's participants were classified as mild-to-moderate TBI severity using GCS scores, the vast majority were considered as having a severe TBI based upon commonly used duration of PTC criteria. Thus, there are definite shortcomings among currently used TBI severity classifications that render making comparisons among studies difficult and threaten the overall accuracy of estimating prognosis after injury. More accurate prognostication and better treatment planning after TBI would likely ensue with the creation and utilization of one standardized classification of TBI severity that relies on injury severity variables beyond GCS scores.

Given the continued reliance on GCS scores in the classification of brain injury severity at present, the current results serve to highlight the importance of CT scanning

even after seemingly mild injuries. Notably, much variability exists both within and across countries in terms of physicians' ordering practices for CT scanning after MTBI. For instance, CT scanning following MTBI is routine practice in the United States and the American College of Surgeons specifically teaches that, other than in instances of clearly trivial head injury, all head-injured patients require CT scanning (American College of Surgeons, 1993). In contrast, European countries are exceptionally selective in their approach to the ordering of CT scanning after MTBI. In Italy, for example, CT scanning is recommended only if a skull fracture has first been identified upon radiography following MTBI (Servadei et al., 1995).

Within Canada, much variability also exists in physicians' CT ordering practices after brain injury. An investigation of CT scanning use in seven Canadian Emergency Departments revealed considerable variation in CT ordering after MTBI that could not be accounted for by differences in patient characteristics or injury severity variables, with CT orders ranging from a low of 16% to a high of 70% (Stiell et al., 1997). Controversy continues regarding recommendations for the use of CT scanning after MTBI in light of some positive findings amidst a generally low yield versus the associated economic cost of routinely using this technology. The findings from the current study add to the controversy by indicating an increased need for CT scanning at medical institutions where such practices are less routine after MTBI. This is particularly important in Canada where 70% of acute care hospitals operate without CT scanners, referring elsewhere instead as needed (Stiell et al., 2001). Although various clinical decision rules for CT scanning after MTBI have been proposed and serve as a first-step toward developing a unified protocol (e.g., Servadei et al., 2001; Stiell et al., 2001), the use of different

definitions of MTBI and the variability of participant inclusion criteria among studies to date has precluded the adoption of any firm guidelines for the use of CT scanning in patients presenting with MTBI.

In summary, the current study extends the findings of short-term cognitive and functional outcome after complicated MTBI and provides a preliminary view of longer-term recovery. Similar neuropsychological and functional outcomes were found after complicated MTBI and moderate TBI to indicate that when classifying severity of TBI based on GCS scores, consideration of a moderate injury designation should be given to persons with an intracranial bleed and a GCS score between 13 and 15.

Several limitations to the generalizability of the findings from the present study must be noted in order to guide future research. Given the exploratory nature of neuropsychological and functional outcome after complicated MTBI at 1-year or more post-injury, replication of the current findings in other complicated MTBI samples using similar inclusion and exclusion criteria is necessary. Notably, the patients with complicated MTBI in the current study all endured intracranial bleeds, thus patients who sustain epidural bleeds or surface scalp abrasions should not be considered equivalent with this group. Of further consideration is the extent to which the complicated MTBI group in the current study represents a subset of the most severely injured patients within this TBI population, given that their injuries were of sufficient severity to warrant inpatient rehabilitation. In this regard, future research should include patients with complicated MTBI who sustain less severe bodily injuries such that hospitalization is minimal post-injury, in addition to patients with uncomplicated MTBI and non-brain injured trauma patients (e.g., orthopedic patients) to serve as control groups. Finally,

although the overrepresentation of men, African Americans, and single persons in the current study is consistent with previous studies of TBI, caution should be exercised in generalizing the findings to TBI populations who differ demographically.

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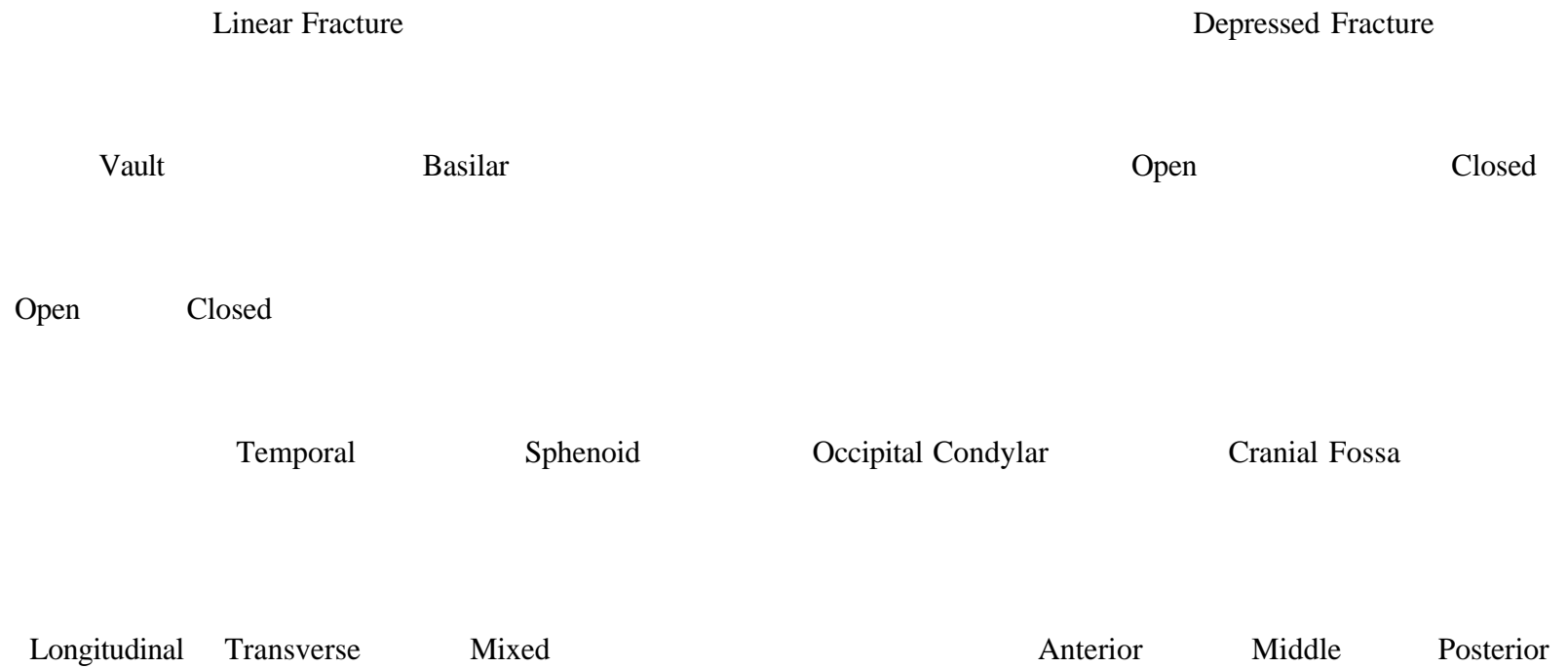
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Appendix A

Classification of Skull Fractures

Skull Fractures



Adapted from Qureshi & Harsh (2006).

Appendix B

Pathology of Closed Head Injury

Type of Insult	Pathology
Primary	Skull fracture Intracranial contusions and hemorrhage Shear-strain injury
Secondary	Brain swelling Cerebral edema Elevated intracranial pressure Hypoxia-ischemia Mass lesion (hematoma)
Neurochemical	Excessive production of free radicals Excessive release of excitatory neurotransmitters Disruption of cellular calcium homeostasis
Delayed	White matter degeneration and cerebral atrophy Posttraumatic hydrocephalus Posttraumatic seizures

Adapted from Yeates (2000).

Appendix C

Glasgow Coma Scale

Category	Score	Description
<u>Eye Opening</u>		
None	1	Not attributable to ocular swelling.
To pain	2	Pain stimulus is applied to chest or limbs.
To speech	3	Nonspecific response to speech or shout; does not imply patient obeys command to open eyes.
Spontaneous	4	Eyes are open, but this does not imply intact awareness.
<u>Motor Responses</u>		
No response	1	Flaccid.
Extension	2	Decerebrate posturing: Adduction, internal rotation of shoulder, and pronation of forearm.
Abnormal flexion	3	Decorticate posturing: Abnormal flexion, adduction of the shoulder.
Withdrawal	4	Normal flexor response; withdraws from pain stimulus with abduction of the shoulder.
Localizes pain	5	Pain stimulus applied to supraocular region or fingertip causes limb to remove it.
Obeys commands	6	Follows simple commands.
<u>Verbal Responses</u>		
No response	1	No vocalization.
Incomprehensible	2	Vocalizes, but no recognizable words.
Inappropriate	3	Intelligible speech (e.g., shouting or swearing) but no sustained or coherent conversation.
Confused	4	Responds to questions in a conversational manner, but the responses indicate disorientation.
Oriented		<u>Normal orientation to time, person, and place.</u>

Glasgow Coma Scale = Eye Opening score + Motor Response score + Verbal Response score (range 3 to 15).

Adapted from Teasdale & Jennett (1974).

Appendix D

Subclassifications of MTBI

Williams et al. (1990)	<u>Uncomplicated MTBI</u> <ul style="list-style-type: none"> • GCS 13-15 • Normal CT scan • Either: <ol style="list-style-type: none"> 1) normal skull x-ray 2) abnormal skull x-ray limited to a linear basilar skull fracture 	<u>Complicated MTBI</u> <ul style="list-style-type: none"> • GCS 13-15 • Radiographic evidence of: <ol style="list-style-type: none"> 1) focal brain lesion 2) depressed skull fracture 3) both 	
Hsiangetal.(1997)	<u>MTBI</u> <ul style="list-style-type: none"> • GCS 15 • No radiographic abnormalities 	<u>High-risk MTBI</u> <ul style="list-style-type: none"> • GCS 13 or 14 • GCS 15 with radiographic abnormalities including: <ol style="list-style-type: none"> 1) skull fracture 2) intracranial hematoma or contusion 3) subarachnoid hemorrhage 	
Servadei et al. (2001)	<u>Low Risk MTBI</u> <ul style="list-style-type: none"> • GCS 15 • No LOC, amnesia, vomiting or diffuse headache 	<u>Medium Risk MTBI</u> <ul style="list-style-type: none"> - GCS 15 • One or more of LOC, amnesia, vomiting, or diffuse headache 	<u>High Risk MTBI</u> <ul style="list-style-type: none"> • GCS 14 • GCS 15 with skull fracture and/or neurological deficits - GCS 15 with one of coagulopathy, drug or alcohol consumption, premorbid neurosurgery, premorbid epilepsy, age > 60

Appendix E

Glasgow Outcome Scale

<u>Score</u>	<u>Description</u>
1	Death
2	Persistent Vegetative State Patient exhibits no obvious cortical function.
3	Severe Disability Conscious but disabled. Patient depends upon others for daily support due to mental or physical disability, or both.
4	Moderate Disability Disabled but independent. Patient is independent as far as daily life is concerned. The disabilities found include varying degrees of dysphasia, hemiparesis, or ataxia, as well as intellectual and memory deficits and personality changes.
5	Good Recovery Resumption of normal activities even though there may be minor neurological or psychological deficits.

Adapted from Jennett & Bond (1975).

Appendix F

Functional Independence Measure

Motor Items

Self-care

Eating
 Grooming
 Bathing
 Dressing upper body
 Dressing lower body
 Toileting

Sphincter Control

Bladder management
 Bowel management

Mobility

Bed, chair, wheelchair transfer
 Toilet transfer
 Tub, shower transfer
 Walking, wheelchair locomotion
 Stairs

Cognition Items

Communication

Comprehension
 Expression

Psychosocial Adjustment

Social interaction

Cognitive Function

Problem solving
 Memory

Levels of Function

Independent

7. Complete independence
 6. Modified independence
 (extra time, devices required)

Modified Dependence

5. Supervision
 (cuing, coaxing, prompting
 required)
 4. Minimal assist
 (performs 75% or more of task)
 3. Moderate assist
 (performs 50% to 74% of task)

Complete Dependence

2. Maximal assist
 (performs 25% to 49% of task)
 1. Total assist
 (performs less than 25% of task)

Adapted from Hall et al. (1996).

Appendix G

Disability Rating Scale

<u>Category</u>	Item	Instructions
	Eye opening	0 = spontaneous, 1 = to speech, 2 = to pain, 3 = none
Arousability, awareness, responsivity	Communication ability	0 = oriented, 1 = confused, 2 = inappropriate, 3 = incomprehensible, 4 = none
	Motor response	0 = obeying, 1 = localizing, 2 = withdrawing, 3 = flexing, 4 extending, 5 = none
	Feeding	0 = complete, 1 = partial, 2 = minimal, 3 = none
Cognitive ability for self-care activities	Toileting	0 = complete, 1 = partial, 2 = minimal, 3 = none
	<u>Grooming</u>	<u>0 = complete, 1 = partial, 2 = minimal, 3 = none</u>
Dependence on others	Level of functioning	0 = completely independent
		1 = independent in special environment
		2 = mildly dependent
		3 = moderately dependent
		4 = markedly dependent
		<u>5 = totally dependent</u>
Psychosocial adaptability	Employability	0 - not restricted
		1 = selected jobs
		2 = sheltered workshop (non-competitive)
		<u>3 = not employable</u>

Disability Categories: None (0); Mild (1); Partial (2-3); Moderate (4-6); Moderately Severe (7-11); Severe (12-16); Extremely Severe (17-21); Vegetative State (22-24); Extreme Vegetative State (25-29).

Adapted from Rappaport et al. (1982).

Appendix H

Community Integration Questionnaire

Who usually does?

1. Shopping for groceries or other necessities (H)
2. Meal preparation (H)
3. Normal everyday housework (H)
4. Caring for children (H)
5. Planning for social arrangements (H)
6. Personal finances (S)
 - 2 = Yourself alone
 - 1 = Yourself and someone else
 - 0 = Someone else
 - 8 = NA

Approximately how many times a month do you participate in the following activities outside your home?

- 7.. Shopping (S)
8. Leisure activities - movies, sports, restaurants (S)
9. Visiting friends or relatives (S)
 - 2 = 5 or more times/month
 - 1 = 1-4 times/month
 - 0 = Never
10. When you participate in leisure activities do you usually do this alone or with others? (S)
 - 2 = Combination of family/friends *or* mostly with friends without head injuries
 - 1 = Mostly with family *or* mostly with friends with head injuries
 - 0 = Mostly alone

11. Do you have a best friend/confidant? (S)

- 2 = Yes
- 0 = No

12. How often do you travel outside the home? (P)

- 2 = Almost every day
- 1 = Almost every week
- 0 = Seldom/never

13. What best describes your current work situation? (P)

- a = Full-time (over 20 hours/week)
- b = Part-time (20 hours/week or less)
- c = Not working - actively seeking work
- d = Not working - not seeking work
- 8 = NA - retired due to age

14. What best describes your current school/training program situation? (P)

- a = Full-time
- b = Part-time
- c = Not attending

15. In the past month, how often did you engage in volunteer activities? (P)

- a = 5 or more times/month
- b = 1-4 times/month
- c = Never

H: Home Integration; S: Social Integration; P: Productive Activities.

Adapted from Wilier et al. (1993).

Appendix I

Neuropsychological Test Descriptions

Block Design Test:

A measure of visuoconstruction ability whereby participants are required to construct block designs matching those shown on a stimulus card.

Controlled Oral Word Association Test:

A word generation task whereby participants are asked to generate as many words as possible beginning with a specified letter within a one-minute time period.

Digits Backward Test:

This test assesses working memory by requiring participants to repeat orally presented numbers in reverse order.

Logical Memory Test:

A story recall task requiring participants to recall two orally presented stories immediately after their presentation (LM1) and after a 30-minute delay (LM2).

Rey Auditory Verbal Learning Test:

Assesses verbal learning and recall by testing the participant's ability to learn a list of 15 unrelated words over five learning trials and recall these words after administration of a second interference word list.

Symbol Digit Modalities Test - Oral:

A test of information processing speed whereby participants must verbalize the number that matches each symbol in a key at the top of the page.

Trail Making Test:

Part A of this test requires participants to draw lines connecting circled numbers in consecutive order. Part B of this test assesses processing speed requires participants to draw lines connecting letters and numbers in an alternating ascending sequence.

Wisconsin Card Sorting Test:

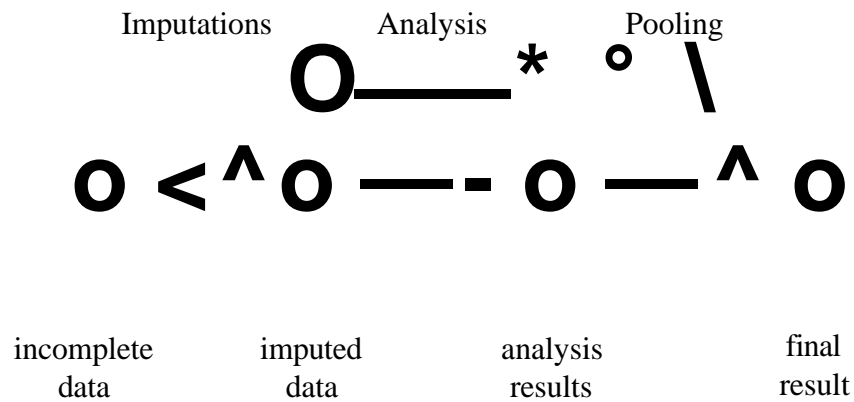
Assesses problem solving and flexibility of thinking by requiring participants to match cards to one of four stimulus cards. Matches are made on the basis of colour, form, or number, with the concept for matching changing at intervals throughout the test. The participant receives feedback regarding the accuracy of each choice as an aid to determining the next appropriate match.

Appendix J

Multiple Imputation Modeling

- Multiple Imputation requires three steps to estimate missing data:
 1. Imputation: Missing data are filled in m times to generate m complete datasets; m random samples are taken from the distribution of the variable with missing data to provide estimates of that variable for each of the m newly created and now complete data sets. Typically 5-10 imputations are created.
 2. Repeated Analysis: The m complete generated datasets are each analyzed separately using standard statistical methods for complete data.
 3. Pooling of Results: The results from the m complete dataset analyses are combined to produce a single point estimate, allowing uncertainty regarding the imputation to be taken into account.

Schematic of the three steps in multiple imputation modeling:



Appendix K

Neuropsychological Performance Impairment Ratings

<u>T-score</u>	<u>Level of Impairment</u>
> 40	Average
35-39	Mildly Impaired
30-34	Mildly-Moderately Impaired
25-29	Moderately Impaired
20-24	Moderately-Severely Impaired
<20	Severely Impaired

Adapted from Heaton et al., 1991.

Normative Conversion Information:

<u>T-score</u>	<u>Z-score</u> <u>(standard deviation)</u>	<u>Percentile</u>
>80	>+3	>99.9
80	+3.0	99.9
70	+2.0	98
60	+1.0	84
50	0	50
40	-1.0	16
30	-2.0	2
20	-3.0	0.1
<20	<-3.0	<0.1

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