A CASE STUDY INVESTIGATION OF THE NEUROPSYCHOLOGICAL PROFILE OF A RUGBY PLAYER WITH A HISTORY OF MULTIPLE CONCUSSIONS

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ABSTRACT

The inherently dangerous nature of Rugby Union predisposes rugby players to a high risk of concussion with a high likelihood of a range of neuropsychological sequelae. Athletes who have sustained multiple concussions may be at risk of cumulative impairment. The role of neuropsychological testing in the management of sports-related concussion is a contentious and challenging issue which has gained credibility given the lack of clear and well-established guidelines pertaining to the diagnosis, assessment and return-to-play decisions following concussion. Despite various traditional paper and pencil tests being shown to be effective indicators of postconcussive neuropsychological dysfunction, testing has not been widely implemented, due to time- and labour-demands. ImPACT, a computer-based neuropsychological assessment instrument, has been recognised as a valid and reliable tool in the monitoring of athletes' symptoms and neurocognitive functioning preseason and postconcussion. As a part of larger-scale concussion research conducted on top-team university rugby players, this is an in-depth case study conducted on a 20-year old participant with a history of multiple concussions, who was referred following a concussion sustained during the season. The objectives of the study were: (i) to determine the sensitivity of ImPACT versus WAIS-III Digit Span and Trail Making Test during the acute postconcussive phase; and (ii) to examine the sensitivity of ImPACT versus a comprehensive battery of neuropsychological tests to possible residual deficits as a result of the multiple concussions. ImPACT was determined to be more sensitive to acute postconcussive impairment following concussion than Digit Span and Trail Making Test. Furthermore, the ImPACT preseason baseline scores appear to be sensitive to neurocognitive dysfunction, possibly due to cumulative concussive injuries.

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CHAPTER 1: LITERATURE REVIEW 1

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'No head injury is too trivial to ignore' (Hippocrates, 460 – 377 BC, in King (2003))

1.1. Contextualisation of concussion

1.1.1. Definition

Cerebral concussion is the most prevalent neurological injury, accounting for at least 90% of all sustained brain injuries (Kashluba et al., 2004) and has gained increased attention in the domains of sports medicine and neuropsychology. Terms such as concussion, cerebral concussion, head injury, mild head injury, mild brain injury and mild traumatic brain injury (MTBI) are often used interchangeably (Echemendia & Julian, 2001). There is currently no universal agreement on the definition of concussion (Cantu, 2001; Covassin, Swanik, & Sachs, 2003). Instead, there is considerable variation in what constitutes a concussion, confounding epidemiological studies, and evaluation and management guidelines (Leclerc, Lassonde, Delaney, Lacroix, & Johnston, 2001). Most definitions of concussion are founded on presenting signs and symptoms at the time of injury (McCrory & Johnston, 2002; Powell, 2001; Rees, 2003), which by their very nature vary widely between individuals (Leclerc et al., 2001).

The Committee on Head Injury Nomenclature of the Congress of Neurologic Surgeons put forward a consensus definition in 1966: a concussion is "a clinical syndrome characterised by immediate and transient post-traumatic impairment of neural functions, such as alteration of consciousness, disturbance of vision or equilibrium due to brain stem involvement" (Theye & Mueller, 2004, p. 167). This definition was subsequently regarded as deficient in its addressing of common concussive symptoms (Pellman et al., 2004), and numerous definitions have since been proposed. In an attempt to provide an inclusive definition for concussion, the American Orthopaedic Society for Sports Medicine (AOSSM) Concussion Workshop detailed the following definition of MTBI: "any alteration in cerebral function caused by a direct or indirect (rotation) force transmitted to the head resulting in one or more of the following signs or symptoms: a brief loss of consciousness, light-headedness, vertigo, cognitive and memory dysfunction, tinnitus, blurred vision, difficulty concentrating, amnesia, headache, nausea, vomiting, photophobia, or a balance disturbance. Delayed signs and symptoms may also include sleep irregularities, fatigue, personality changes, an inability to perform usual daily activities, depression, or lethargy" (Leclerc et al., 2001, p.630). There are difficulties with this definition, however, as the only symptoms which have been scientifically validated are loss of consciousness, headache, dizziness, nausea, blurred vision, amnesia and attentional deficit (Leclerc et al., 2001; McCrory & Johnston, 2002).

In 2001, the First International Conference on Concussion in Sport was held in Vienna (referred to as the "Vienna Conference" for the purposes of this discussion) (Aubrey et al., 2002) to elucidate a comprehensive, standardised approach to MTBI management. Recently, the Second International Conference on Concussion in Sport took place in Prague (the "Prague Conference") (McCrory et al., 2005) where issues pertaining to sports-related concussion were further consolidated and ratified. With regard to a definition of concussion, there was little change made to the proposed definition from the Vienna Conference:

> Sports concussion is defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces. Several common features that incorporate clinical, pathologic and biomechanical injury constructs that may be utilised in defining the nature of a concussive head injury include:
>
> 1) Concussion may be caused either by a direct blow to the head, face, neck or elsewhere on the body with an "impulsive" force transmitted to the head.
>
> 2) Concussion typically results in the rapid onset of short-lived impairment or neurologic function that resolves spontaneously.
>
> 3) Concussion may result in neuropathological changes but the acute clinical symptoms largely reflect a functional disturbance rather than structural injury.
>
> 4) Concussion results in a graded set of clinical syndromes that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course.
>
> 5) Concussion is typically associated with grossly normal structural neuroimaging

studies (McCrory et al., 2005, p.48)

The only difference between the definitions emerging from the two conferences was the observation that postconcussive symptoms "may be prolonged or persistent" in certain cases (McCrory et al., 2005, p.49).

1.1.2. Classification of severity

The pathophysiology of TBI occurs along a continuum of mild concussive injuries which are hardly noticed and result in no sequelae, to severe, diffuse damage giving rise to long-term vegetative conditions or death (Bailes & Hudson, 2001; Hannay, Howieson, Loring, Fischer, & Lezak, 2004).

In 1966, the Subcommittee on Classification of Sports Injury first devised a concussion grading system where concussions were ranked along a continuum of mild, moderate and severe (Guskiewicz, Bruce et al., 2004). Since this time at least fourteen concussion classification tools have been formulated to identify indicators of severity to guide treatment and recovery (Collins, Lovell, & McKeag, 1999; Echemendia & Julian, 2001). Like the definitional difficulties discussed previously, there is little consensus and clarity regarding grading of concussion injuries and the priority accorded to various symptoms (Theye & Mueller, 2004). The Glasgow Coma Scale (GCS) has been extensively applied to classify MTBI according to the incidence, degree and length of loss of consciousness (LOC) (Hannay et al., 2004). Kelly (2001) asserts that despite idiosyncratic recovery rates, there is scientific evidence that concussion associated with LOC represents a more severe brain injury than a concussion without LOC. However, numerous studies suggest that there are limitations in using LOC as an indicator of severity of MTBI (McCrory et al., 2005). Alternatively, various classification scales place prominence on the presence and duration of post-traumatic amnesia (PTA) as a sensitive indicator of severity and predictor of outcome, yet there is currently no consensus regarding the association between the duration of PTA and recovery from concussion (Cantu, 2001; McCrory et al., 2005).

Recently, three concussion classification scales have been widely implemented, each attributing varying significance to the presence of LOC and PTA (Echemendia & Julian, 2001). These grading systems, namely the Cantu, Colorado and American Academy of Neurology guidelines, differ with regard to the criteria for classifying concussions as mild, moderate or severe (Echemendia & Julian, 2001), and each system has its own corresponding set of return to play guidelines (Echemendia & Cantu, 2003).

The Cantu concussion grading scheme accords emphasis to amnesia, stating that a mild (grade 1) concussion (the type of concussion seen most frequently in athletes) is one with confusion, or a brief (less than 30 minutes) period of amnesia, and no LOC (Bailes & Hudson, 2001). According to the Colorado guidelines, confusion without LOC represents a grade 1 concussion, while the American Academy of Neurology associates mental status abnormalities of 15 minutes and less, and no LOC, as a mild concussion (Bailes & Hudson, 2001). Thus, according to the AAN classification system, symptoms such as disorientation, memory difficulties, confusion, dizziness, headache or other neuropsychological difficulties which persist longer than 15 minutes would mean that the athlete has sustained more than a mild concussion. Cantu defined a moderate (grade 2) concussion as one with less than a 5 minute period of LOC, or post-traumatic amnesia with a duration between 30 minutes and 24 hours. In contrast, the Colorado guidelines classify a moderate concussion as one accompanied by amnesia and no LOC. A moderate concussion, according to AAN guidelines, would involve mental status changes for longer than 15 minutes without LOC. According to Cantu guidelines, a severe (grade 3) concussion is one with LOC longer than 5 minutes or more than 24 hours PTA (Bailes & Hudson, 2001).

Although these classification systems offer a helpful means for communication regarding concussion injury, and direct attention to return to play decisions (Echemendia & Julian, 2001), Cantu (2001) cautions that they may accord insufficient significance to the diverse presentation and combination of postconcussive signs and symptoms. Moser and Schatz (2002) express concern that the "fleeting bell-ringing" (p.93) which occurs frequently at all levels of play is often underreported or dismissed. Although AAN guidelines may classify this injury as a

Grade 1 concussion, it may not be accorded sufficient significance from a research and/or medical management perspective. Furthermore, McCrory (2001c) asserts that guidelines pertaining to severity of TBI are mostly controversial and lack a valid empirical foundation.

Guidelines from the Prague Conference (McCrory et al., 2005) documented difficulties with the assessment of the severity of concussion prior to neurological examination, neuropsychological assessment, and the resolution of postconcussive symptoms. Citing a paucity of published evidence, the conference highlighted the poor correlation between the severity of concussion and the number and duration of postconcussive symptoms and/or degree of neuropsychological impairment. Accordingly, it was recommended that injury classification scales are discarded and replaced by a more individualised approach using a variety of measures to determine injury severity and direct treatment (McCrory et al., 2005). In seeming contradiction to this recommendation, however, the Prague Conference put forward a distinction between "simple" and "complex" concussion, delineating management decisions regarding return to play (McCrory et al., 2005). In terms of these definitions, a simple concussion, the type most frequently experienced by athletes, is one which "progressively resolves without complication" (p.50) in the 7 to 10 days following head trauma. A complex concussion is characterised by enduring symptoms, LOC exceeding one minute, or persistent neurocognitive deficits (McCrory et al., 2005). Athletes who have experienced multiple concussions may be allocated to the complex concussion category. Guidelines from the Prague Conference, however, are vague with regard to the usefulness of this distinction as it would seem that discernment between simple and complex concussions can only be made retrospectively, generating associated management difficulties.

1.1.3. Pathophysiology

Cerebral concussion occurs as a result of blunt trauma or forces of acceleration, deceleration and rotation to the head (Hannay et al., 2004; Ponsford, Sloan, & Snow, 1995) which bring about various structural and functional changes to the brain (Giza & Hovda, 2001; Rutherford, Stephens, & Potter, 2003).

1.1.3.1. Diffuse axonal injury (DAI)

Rotational acceleration and deceleration forces frequently result in diffuse axonal injury (DAI) which involves the shearing and contusion of brainstem axons and intercranial blood vessels (Hannay et al., 2004; Rutherford et al., 2003). Similarly, rotational forces may sever and disrupt axon fibres, creating small localised regions of haemmorhage (Bailes & Hudson, 2001). This may result in structural impairment as well as changes to the neural cell membrane structure with possible consequences on neurochemical function (Echemendia & Julian, 2001). Severe DAI may impair brain-stem centres which are responsible for breathing, heart rate, and wakefulness (Guskiewicz, Ross, et al., 2004).

1.1.3.2. Neurochemical dysfunction

Neurochemical difficulties have been experimentally and clinically identified during the first several days post-MTBI (Bailes & Hudson, 2001). Concussive injury results in the activation of a glycolytic process to compensate for ionic abnormalities at a cellular level. This metabolic dysfunction gives rise to neurovascular vulnerability as there is an increased demand for glucose with concomitant impairment of cerebral blood flow (Bailes & Hudson, 2001; Giza & Hovda, 2001; Echemendia & Julian, 2001; Wojtys et al., 1999). This process renders the brain in a vulnerable state as there is an imbalance between energy production and demand (Bowen, 2003). The duration of metabolic dysfunction is unknown, and there are currently no neuroanatomic or physiologic measurement tools that are able to precisely determine the extent of concussive injury or the extent of metabolic dysfunction or resolution (Cantu, 2001).

Second Impact Syndrome (SIS): The lack of knowledge pertaining to neurochemical consequences of concussion may result in premature return to play decisions being made before the complete resolution of the injury. This has been held responsible for a rare, but potentially fatal phenomenon known as Second Impact Syndrome (SIS) (Echemendia & Julian, 2001), or more minor neuronal attrition that is cumulative over time (Bowen, 2003). Studies have implicated SIS in at least 17 deaths between 1992 and 1997, with adolescents between the ages of 13 and 18 most at risk for SIS (Lovell et al., 2003; Sadovsky, 2004).

Second Impact Syndrome can occur in sports in which athletes sustain successive blows to the head. The first injury results in cerebral oedema with consequent metabolic dysfunction, vascular congestion, and intracranial hypertension, which leaves the athlete symptomatic. A second impact, even if minor, may rapidly give rise to massive cerebral oedema with consequent brain herniation (Echemendia & Julian, 2001). According to Echemendia and Julian (2001), the athlete will usually collapse within minutes of the second injury marking the onset of a "neurological crisis" (p.73).

The existence of SIS is a controversial one. McCrory (2001a) argues that there is presently insufficient support for SIS. In his review of published evidence for and against SIS, McCrory (2001a) asserts that rather than being a complication of multiple concussions, what is commonly identified as SIS is more likely a diffuse cerebral oedema, and therefore, a common clinical consequence of MTBI.

1.1.3.3. Other secondary consequences

The brain is supported within the skull by cerebrospinal fluid and three protective dural membranes which attach at various locations on bony irregularities within the skull (Guskiewicz, Bruce, et al., 2004; Rutherford et al., 2003). Due to the brain's limited capacity for movement within the skull, a forceful blow to the head may result in contact of the brain and the dural membranes to these inner bony ridges. The outcome of this may be shearing and contusion of the cortical surface, or damage to the dural membranes, or their points of attachment to the cranium (Bailes & Hudson, 2001; Rutherford et al., 2003). Potentially life-threatening intracranial space-occupying lesions in the form of epidural, subdural or intracerebral haematomas may result (Bailes & Hudson, 2001; Kohler, 2004).

1.2. Neuropsychological sequelae of concussion

There is a strong likelihood of neuropsychological impairment following MTBI (Killam, Cautin, & Santucci, 2005). Sequelae of MTBI are usefully differentiated as (i) neurocognitive dysfunction, determined through objective assessment measures following MTBI, and (ii) postconcussive symptoms (Shuttleworth-Edwards, Border, Reid, & Radloff, 2004). Unlike more conspicuous forms of head trauma which frequently result in clear neuropsychological deficits, the subtle nature of MTBI may produce unobtrusive, but potentially serious and permanent impairment (Grindel, Lovell, & Collins, 2001).

Various studies have been conducted using objective measures in the identification of neurocognitive changes which may result from MTBI, including attention and concentration, memory, information processing, motor speed, planning and cognitive flexibility (Barth et al., 1989; Erlanger, Saliba, et al., 2001; Guskiewicz, Ross, et al., 2001). Sport concussion assessment is making increasing use of neurocognitive screening tools in the evaluation of changes in cognitive functioning following MTBI and during recovery (Guskiewicz, Bruce, et al., 2004) (this will be addressed in greater detail later in this chapter, p. 20).

By their very nature, symptoms of concussion are subjective and frequently vague (Barr, 2001). An individual may appear to have made a complete clinical recovery, but may continue to complain of a variety of physical and emotional difficulties (Richardson, 1990). These symptoms have been incorporated into a number of concussion severity grading scales (Guskiewicz, Bruce, et al., 2004). Although these symptoms commonly resolve after a few days, they can persist for a number of weeks, or even months following the injury (Richardson, 1990). Typical postconcussive symptoms reported, include fatigue, poor concentration, memory difficulties, irritability, aggression, anxiety, depression, dizziness, blurred vision, insomnia, and speech problems (Barth et al., 1989).

Various studies have shown that athletes who suffer multiple concussions may be at risk of developing postconcussive syndrome (PCS), a debilitating condition characterised by the development and persistence of various symptoms including headache, dizziness, disorientation and impaired balance, motor function slowing, altered sensation, photophobia, nausea, emotional lability, tinnitus, slowed information processing, attention difficulties and memory problems (Grindel et al., 2001; Lovell, & Collins, 2002; Richardson, 1990; Slobounov, Sebastianelli, & Simon, 2002).

In a seminal article, Lishman (1988) posits that physiological features bring about PCS, while mostly psychological factors contribute to the enduring nature of the syndrome. In this regard, 'psychogenesis' and 'physiogenesis' are often perceived as mutually exclusive explanations for PCS (Lishman, 1988), yet it is possible that the condition represents a combination of various factors, such as pre-morbid vulnerability, postinjury adjustment, and postinjury neurocognitive impairment (Yeates & Taylor, 2005). It is therefore difficult to identify a specific cause for PCS, because "objective intracranial or extracranial anatomic pathology is rare" (Slobounov et al., 2002, p.186) and there is the potential that the interaction of cognitive, behavioural, and emotional features may produce symptoms constituting PCS. As a result, PCS may be maintained through the complex interface of factors such as the "initial injury severity, other bodily injuries and chronic pain, comorbid depression, psychosocial stressors (including litigation stress), or misattribution of everyday symptoms" (Iverson, Lovell, & Smith, 2000, p.644).

Postconcussive syndrome is fairly uncommon in most collision and contact sports, although there have been insufficient studies that have tracked athletes for significant periods (McCrory & Johnston, 2002). The existence of a postconcussive syndrome, rather than simply the presence of various postconcussive symptoms, is a controversial one (McCrory & Johnston, 2002). There is disagreement regarding the permanent neurophysiological and neuropsychological effects of PCS (Slobounov et al., 2002). McCrory (2001b) asserts that this constellation of symptoms indicates a global cerebral dysfunction, rather than focal injury.

1.2.1. Recovery of function

Neuropsychological sequelae of concussion, such as cognitive impairment, physical complaints, and emotional disturbances usually resolve between one to three months following the injury (Barth et al., 1989; Macchiochi et al., 1996; Maroon et al., 2000), although some athletes may manifest persistent and disabling symptoms (Wojtys et al.,1999). According to Slobounov et al. (2002), long-term deleterious effects of concussion are often disregarded as the concussive injury appears inconsequential and the obvious sensory-motor difficulties resolve quickly.

A study conducted by Matser, Kessels, Lezak, Troost, & Jordan (1998) investigating cognitive effects following concussion in amateur soccer players, identified impairments in planning, memory, and visuospatial skills related to the number of concussions experienced by athletes. Research conducted by Barth in 1998 and Barth et al. in 1989 into the neuropsychological effects of concussion on college football players evaluated athletes at three intervals postinjury (cited in Moser & Schatz, 2002). Significant cognitive impairment, relative to preseason functioning, was detected with regard to memory, attention and problem-solving immediately following the concussive injury. These athletes were reported to return to their baseline level of cognitive functioning within five to ten days postconcussion (Moser & Schatz, 2002; Webbe & Barth, 2003). However, complete recovery following multiple concussions or subconcussive injuries may be more complicated (Webbe & Barth, 2003).

The incidence and recovery from memory impairment and subjective self-reported symptoms following MTBI in high school athletes were evaluated in a study conducted by Lovell et al. (2003). Extended aspects of this research included an investigation into the relationship between the duration of on-field signs and symptoms of concussion and recovery of memory performance one week following the cerebral insult, and the relationship between self-reported postconcussive symptoms and neuropsychological test results. The control group performed at a similar level of memory function as the athletes throughout the testing process. However, significant discrepancies in memory functioning were evident between athletes with short-lived and those with more prolonged alteration of mental status, with athletes with more enduring on-field symptoms presenting with greater memory impairment postconcussion (Lovell et al., 2003). Further, in this study it was established that even relatively minor concussions may result in marked memory difficulties which may persist several days postinjury, with more severe head injury producing memory impairment which may last for at least 7 days following the concussion (Lovell et al., 2003). Importantly, this study showed a marked discrepancy between objective neuropsychological assessment results and subjective self-report symptom checklists. As a result of the unreliability and inconsistency of athlete self-report scales (which are the most commonly used methods in return to play decisions in schools and many colleges), Lovell et al. (2003) assert that this study presents strong evidence for the standard application of neuropsychological evaluation for athletes, both preseason and postinjury, in order to assist with return to play decisions.

With regard to the subjectively experienced symptoms reported in both the general population and athletes, an extensive literature search has revealed numerous investigations into the recovery of function following MTBI. Most studies have focused on acute effects of concussion, such as alteration in consciousness, headache, amnesia, confusion and disorientation, slowed cognitive processing, and irritability, while there have been relatively few long-term follow-up studies into chronic difficulties (Moser & Schatz, 2002). Research suggests that most postconcussive symptoms are resolved within three months following injury (Kashluba et al., 2004). Although most individuals report a complete recovery in this time, around 8% report persistent symptoms one year postinjury, and an unidentified minority experience possibly permanent complaints following concussion (King, 2003). The recovery of postconcussive symptoms and neurocognitive impairments may not occur simultaneously, and for this reason the assessment of recovery in these areas should be undertaken separately (Lovell & Collins, 2002).

A limitation of many of the available studies is that they do not follow the same subject sample over time. One longitudinal study conducted in 2000 by Ponsford et al. (cited in Kashluba et al., 2004) compared MTBI symptoms in a large patient sample with symptoms reported by control patients with other injuries. This investigation revealed that symptoms reported in the week following the injury, had largely resolved within three months. Participants who remained symptomatic three months postinjury were largely found to have a history of previous head injury, or preexisting neurological or psychiatric complaints (Kashluba et al., 2004). In a study conducted by Levin et al. (1987) the majority of MTBI patients were found to make a complete cognitive recovery within one to three months following the head injury. Slight neurobehavioural impairment was noted in a few individuals, however these were mostly linked to individuals with a history of psychiatric problems or substance abuse. Likewise, a history of prior concussions, and learning disabilities, have been identified as significant factors in individuals presenting with more chronic neurocognitive impairment postconcussion (Moser & Schatz, 2002).

There has been limited research conducted into the cognitive effects of sports-related concussions in young athletes (Moser & Schatz, 2002). In their development of a standardised sideline baseline and screening assessment tool, McCrea et al. (2003) have collected a significant amount of data pertaining to orientation, immediate and delayed memory, and concentration, for 141 high school athletes. This research has identified that lower cognitive performance postconcussion is common in those athletes who have sustained concussions during the season (Moser & Schatz, 2002).

Terrell (2004) recommends that it is essential that long-term prospective studies are conducted in order to determine significant factors associated with chronic MTBI (Terrell, 2004). A research area pertaining to the chronicity of postconcussive symptoms that is currently lacking is one which specifically tracks the pattern of neurobehavioural impairment and recovery following MTBI (Hartlage, Durant-Wilson, & Patch, 2001).

1.2.2. Cumulative MTBI

A history of concussion has been identified as a significant risk factor for further concussions (Schultz et al., 2004; Webbe & Barth, 2003). In contact sports this may be attributed to environmental and behavioural factors such as increased exposure time during games and practices, and/or exposure due to "intense athletic activity ... because of their individual or team style of play" (Schultz et al., 2004, p.943). A player who has sustained one concussion is three to six times more likely to incur a second concussive injury (Cantu, 2001). Athletes involved in contact sports have a significant degree of exposure to the possibility of concussion, and therefore are at a greater risk of developing chronic deleterious sequelae (Shuttleworth-Edwards et al., 2004). These cumulative consequences may be present at subconcussive levels (Naunheim, Standeven, & Baly, 2003).

Of particular concern is the finding that the consequences of multiple concussions, even when slight, may be cumulative (Echemendia & Julian, 2001; Lovell & Collins, 1998; Maroon, Lovell, Norwig, Podell, Powell, & Hartl, 2000). Various research studies conducted into sequelae following sports-related concussion have revealed fairly inconsistent findings. A single concussion does not appear to result in prolonged sequelae, although there is less consensus regarding the effects of multiple concussions (Grindel et al., 2001; Macchiochi, Barth, Littlefield, Cantu, 2001). Chronic neurocognitive dysfunction commonly associated with sports-related concussion is thought to result from multiple concussions (Iverson et al., 2003). According to Grindel et al. (2001), multiple concussions, particularly with close temporal proximity, may result in chronic and sometimes permanent neurocognitive impairment, and may increase the risk of PCS.

In a study conducted by Collins, Lovell, Iverson et al. (2002), neuropsychological and neurobehavioural functioning of athletes with a history of a single concussion was compared with athletes with more than one concussion. Increased neurobehavioral symptoms and neuropsychological dysfunction were evident in athletes with a history of multiple concussions (although this did not apply to auditory attention, verbal fluency, verbal learning, verbal memory, or fine motor dexterity). Findings of a study conducted by Iverson, Gaetz, Lovell & Collins (2003), indicate that athletes who have a history of multiple concussions performed more poorly on baseline memory tasks, and reported more symptoms than age-appropriate controls who had not sustained a concussion. Moreover, athletes with a history of multiple concussions exhibited more pronounced on-field severity markers with their subsequent concussion than athletes experiencing their first concussion. The athletes with a multiple concussion history also demonstrated increased acute neuropsychological impairment subsequent to the next concussion than the athletes with one concussion (Iverson et al., 2003).

Consistent findings were reported in a study conducted by Gaetz et al (cited in Iverson et al., 2003) where baseline testing of athletes with a history of more than three concussions revealed substantially more postconcussive symptoms than those of athletes with no prior concussions. Similarly, a study conducted by Killam et al. (2005) investigated chronic neuropsychological sequelae among college athletes. Findings from this study suggest that neuropsychological impairment, particularly in memory, occurs following concussion, but that this resolves in time. Furthermore, there is evidence that sub-concussive injuries common in contact sports may play a significant role in cumulative effects of multiple MTBI (Killam et al., 2005).

Studies into the cumulative effects of multiple concussions have not, however, yielded consistent results (Iverson, Gaetz, et al., 2003). A study conducted by Guskiewicz et al. in 2000 (cited in Schultz et al., 2004) found no correlation between chronic cognitive dysfunction and a history of mild concussions among collegiate soccer players. A prospective research design aimed at comparing pre- and post-test neurobehavioural and neuropsychological functioning of college athletes who have sustained one concussion, with athletes with two concussions, found no difference in neurocognitive performance between athletes from these groups (Macchiochi et al., 2001). Further, neuropsychological testing did not reveal more pronounced dysfunction relative to testing after the first concussion. A confounding finding from this study was that athletes with two concussions exhibited improved performance on postseason assessment relative to preseason baseline testing. Of interest, the self-reported postconcussive symptoms were found to differ significantly between the group of athletes with one concussion and those with two concussions; however symptom reports for both groups generally returned to baseline within 10 days following the injury (Macchiochi et al., 2001). Although the researchers acknowledge the methodological limitations of this study which prevent these findings from being generalised to other populations vulnerable to frequent or more severe concussive injuries, they highlight the significance of self-reported symptoms as highly sensitive indicators of neuropsychological dysfunction.

In a study to extend existing research, Moser and Schatz (2002) investigated enduring sequelae of MTBI in youth athletes. Findings suggest mild, persistent consequences following concussion particularly in youth athletes who have experienced a history of two or more concussions. General neuropsychological functioning was negatively affected, in particular impaired attention and information processing speed. Moser and Schatz (2002) speculate that this study on young athletes, and the apparent contrasting results obtained by Macchiochi et al (2001) in respect of young adults, may point to differences in recovery curves between adolescents and young adults, perhaps emphasising the view that the still-developing brain in adolescents is more vulnerable to cerebral insult than that of adults.

Giza and Hovda (2001) stress the significance of proper contextualisation of postconcussive pathophysiology when assessing injury severity and management guidelines, and consideration of the time-frame between two concussive injuries may be an important determinant of outcome prediction. Similarly, in his analysis of research of neurocognitive impairment following MTBI, Cantu (2001) posits that shearing of nerve fibres is proportional to the forces of impact occurring during head trauma, and that these injuries may be cumulative. Multiple cerebral concussions may therefore have significant consequences on the severity and persistence of neuropsychological dysfunction particularly with regard to processing speed (Cantu, 2001).

Adult studies have suggested a link between multiple concussive injuries and long-term sequelae, and increasing awareness is being accorded the possibility that recurrent MTBI may result in permanent brain damage (Kohler, 2004). In particular, a relationship between Apolipoprotein 4 gene (ApoE), a factor associated with Alzheimer's disease, and an increased risk of chronic neuropsychological sequelae has been identified (Kohler, 2004; Moser & Schatz, 2002). Extended research is indicated, with a focus to clarify the link between injury severity and duration of cognitive deficits (Kohler, 2004). Moreover, if there is a correlation between multiple

MTBI and chronic neuropsychological impairment, appropriate concussion management should require that this information is related to athletes and their families in order that informed decisions regarding sports participation can be taken (Iverson, Gaetz, et al., 2003).

1.2.3. Brain Reserve Capacity (BRC) Theory

Significant variation has been found between individuals with regard to the presence, severity and duration of neurocognitive deficits following TBI (Kesler, Adams, Blasey, & Bigler, 2003). According to Brain Reserve Capacity (BRC) theory, individual differences determine a threshold factor, representing vulnerability to, or protection from, symptomatic presentation following cerebral trauma (Satz, 1993). When the extent of brain injuries sustained reaches this threshold, clinical manifestations of the cerebral damage occur (Kesler et al., 2003). Premorbid features (for instance, previous head injuries, previous or existing neurological or psychiatric disorders), as well as demographic characteristics (such as age, IQ and education) are considered to contribute to an individual's vulnerability to chronic neuropsychological effects (Kesler et al., 2003).

In a critical review of theoretical issues and previous studies pertaining to cognitive reserve, Stern (2002) posits that an estimate of IQ or premorbid IQ may be a significant indicator of reserve. In addition, studies suggest that education further contributes to the reserve arising from intelligence (Stern, 2002). Similar findings arose from a study conducted by Kesler et al. (2003) in which individuals with smaller brain volumes (brain volume has been strongly correlated with IQ in previous studies) and lower education are at greater risk of functional impairment following TBI, especially with regard to IQ outcome, despite injury severity and degree of structural cerebral damage.

In a study by Collins, Grindel, Lovell, et al. (1999) prior concussion history and learning disabilities have been independently linked to sub-normal performance in the following areas of cognitive functioning: executive functioning, information processing speed, timed word fluency, and memory (Collins, Grindel, Lovell et al., 1999). It would appear that as a result of the reduced cerebral reserve in athletes with learning disabilities, athletes suffering MTBI may have a stronger predisposition to present with neurological impairment than those athletes without learning disabilities. Collins et al. argue that despite the relatively small sample size, the research strongly motivates for the use of comprehensive neuropsychological assessment during the acute and follow-up management of a concussed athlete.

1.3. Concussion and Contact Sports

Cerebral concussion is the most common and pervasive injury among athletes in contact sports at professional, college, and high school levels of play (Bailes & Hudson, 2001; Collie, Darby, & Maruff, 2001; Echemendia & Julian, 2001). The nature of certain sports predispose athletes to multiple concussions, and therefore, possible cumulative cognitive impairment, and highlight the need for proper assessment and management of MTBI (Collie, Darby, & Maruff, 2001). In contact sports, concussion usually results from trauma to the head, although it may also occur in noncontact sports, often as a result of falls (Randolph, 2001). According to Bailes and Hudson (2001), acceleration-deceleration energy forces are implicated in the majority of MTBIs incurred in football, ice hockey, and boxing. Rotational forces, such as whiplash injuries, can cause concussion without a direct blow to the head (Randolph, 2001). Similarly, boxing head injuries may also result from a boxing hook punch that includes a rotational component (Bailes & Hudson, 2001).

1.3.1. Epidemiology

Athletes participating in boxing, ice hockey, some martial arts, baseball, and football (including soccer, American football, Australian Rules football, Rugby League and Rugby Union) have been shown to exhibit signs of cognitive dysfunction following head injury (Collie et al., 2001; Kohler, 2004; Matser, Kessels, Lezak, Troost, & Jordan, 2000). The link between contact sports and deficits in neuropsychological functioning following MTBI has been accorded increasing attention, and incidence reports confirm the significance of this relationship (Barth et al., 1989).

Most MTBI incidence studies have been conducted in the United States and indicate alarmingly high figures of concussion among high school and collegiate athletes involved in contact sports (Lovell et al., 2003). A report on MTBI presented to the United States Congress (National Centre for Injury Prevention and Control, 2003) states that during 1999, sports-related injuries were responsible for 20% of the 1.5 million MTBIs in the US alone. Similarly, in the US, it is estimated that 63% of MTBI are the result of football injuries, with high school athletes most at risk of injury due to their high participation levels (Lovell et al., 2003). A recent study has estimated that there are approximately 62 000 cases of MTBI in US high schools each year (Bailes & Hudson, 2001), although Powell (2001) notes that some authors put this number at closer to 200 000 concussions annually. At high school level, the sports in which athletes are most likely to incur a concussion are football (63.4%), girls' and boys' soccer (11.9%), and wrestling (10.5%) (Moser & Schatz, 2002).

At a college level, an incidence report issued by National Collegiate Athletic Association (NCAA) estimated a concussion rate of 4.2 for every 1000 football exposures (Grindel et al., 2001). In soccer, MTBI accounts for 7% and 11% of injuries sustained in men and women's games respectively. Men's ice hockey is estimated to involve a concussion rate of 1.9 per 1000 athlete exposures. Records indicate that 8% of all game injuries in women's basketball are the result of concussion (Grindel et al., 2001). Highlighting the need for proper information to be given to athletes regarding symptoms and effects of concussion, Echemendia & Julian (2001) report findings of research conducted by Delaney et al. (2000) from the Canadian Football League during the 1997 season. In a retrospective study, 44.8% of football players experienced MTBI symptoms, although only 18.8% realised they had a concussion. This study found that 69.6% of these athletes sustained more than one concussion during the season (Echemendia & Julian, 2001).

Research conducted in South Africa indicates that inherently dangerous tackles, rucks and mauls in the sport of Rugby Union, the mode of rugby football played in South Africa, predispose players to a high risk of MTBI (see review in Shuttleworth-Edwards et al., 2004). Although some players make use of mouth guards and head protection, the efficacy of these devices in protecting players from the powerful collision forces of acceleration, deceleration and rotation, is still being investigated (Marshall & Spencer, 2001). The incidence of concussion amongst rugby players at a South African high school in one season has been determined as 21.5%, and the likelihood of MTBI increases as players compete at more advanced levels (as cited in Shuttleworth-Edwards et al., 2004). Moreover, concussion was noted as the most common injury reported during the 1999 Super 12 rugby competition, with an incidence of 20% likelihood of concussion being reported (Kohler, 2004).

1.3.2. Evaluation and Monitoring of Concussion Sequelae

1.3.2.1. Neuroimaging

The evaluation and monitoring of recovery from concussion in sports has been impeded due to difficulties with current neuroimaging techniques. Although established neurodiagnostic methods, including CT scan, MRI, and neuroanatomic examination are clinically useful in detection of severe neurological pathology, these techniques are unable to identify the often-slight neuropsychological changes following head injury (Guskiewicz, Bruce, et al., 2004; Echemendia & Cantu, 2003; Echemendia & Julian, 2001). McCrory (2001c) posits that this may be attributed in part to concussion being the effect of "a functional rather than structural lesion" (p.146). More recent techniques such as single photon emission computer tomography, positron emission tomography, functional MRI, and magnetoencephalography are being refined and show potential to detect subtle structural abnormalities incurred through MTBI in the future (Echemendia & Julian, 2001; Mathias, Beall, & Bigler, 2004).

1.3.2.2. Neuropsychological testing

Neuropsychological tests have progressively gained credibility in sport concussion literature. They are considered the most sensitive method of identifying postconcussive neurocognitive impairments (Maroon et al., 2000; McCrea, Kelly, Randolph, Cisler, & Berger, 2002) and may enhance understanding of cerebral structure and pathophysiological processes involved in MTBI and PCS (Collie & Maruff, 2003). The value of neuropsychological testing in determining acute and chronic postconcussive sequelae has been investigated in various studies in the past two decades, mostly studies conducted on adult male athletes in football, soccer and rugby (Grindel et al., 2001). Pioneering studies on college football players revealed the significance of neuropsychological tests in describing the severity and course of concussion-related neurocognitive dysfunction (Barth et al., 1989; Macchiochi et al., 1996).

These research findings have prompted many athletics programmes to implement preseason neuropsychological screening to establish an individual baseline level of functioning across several cognitive domains including motor functioning, visual memory, verbal memory, concentration, information processing speed, and executive functioning (Guskiewicz et al., 2004; Randolph, 2001). Follow-up testing is then conducted within 24 to 48 hours postinjury, with serial testing occurring when necessary to determine injury severity and recovery (Barr, 2003; Guskiewicz et al., 2004). Issues pertaining to reliability, validity, and the sensitivity of these tests when compared with alternate concussion indicators such as athlete self-report of postconcussive symptoms and neuroimaging methods have received ongoing scrutiny and discussion (Lovell, 2002).

1.3.2.3. Traditional paper and pencil tests

Traditional paper and pencil neuropsychological testing has offered clinically useful methods for assessing and monitoring neurocognitive impairment and recovery from MTBI (Wotjys et al., 1999). Despite their widespread use, however, consideration should be given to methodological limitations pertaining to reliability, validity, sensitivity and specificity (Grindel et al., 2001). These tests are sometimes unable to detect mild or very subtle neurocognitive deficits which may manifest in athletes with MTBI (Collie et al., 2001; Kohler, 2004). For example, reaction time, a cognitive domain highly sensitive to head injury, may differ between concussed and noninjured individuals by margins of 110 ms or less, and this degree of assessment specificity cannot be achieved through traditional paper and pencil measures (McKeever & Schatz, 2003). Moreover, questions exist pertaining to the reliability of these tests due to the lack of sufficient successive studies (Lovell, 2002), and difficulties associated with practice effects of these tests may negatively influence interpretation of test results during the postconcussive period (Barr, 2003; Collie et al., 2001; Lovell, 2002).

Although there has been fairly extensive application of traditional paper and pencil neuropsychological testing in sports concussion research, this has mostly taken place among professional players, largely as a result of practical and psychometric drawbacks (Collie & Maruff, 2003). The administration and interpretation of these tests is time-consuming and costly, requiring trained personnel, and one individual is usually tested at a time. Most of the studies conducted to date pertaining to neurocognitive impairment and recovery following MTBI in sport, have focused on group research. Due to the associated time constraints in dealing with large numbers of subjects, fairly limited testing has been implemented, especially in the acute follow-up phase. Such testing as frequently comprised only one or two paper and pencil tests, or more recently one of a series of computerised neurocognitive screening measures developed for use in the sports concussion management arena. However, in terms of the deficit measurement method of Lezak et al., (2004) (which will be discussed in more detail at a later stage in this chapter), a more wide-ranging battery of neurocognitive tests would be indicated for the management of a more complex case where recovery is uncertain. This would include assessment of an objective estimate of premorbid functioning, against which patterns of dysfunction on tests sensitive to diffuse brain damage are evaluated. To the author's knowledge, there are no case-based studies of this type reported in the sports concussion literature.

1.3.2.3. Computer-based neuropsychological screening

To overcome the limitations of traditional paper and pencil tests, computerised neurocognitive screening programmes have been developed to augment the application of neuropsychological testing among athletes (Collie & Maruff, 2003). Rather than claiming to be comprehensive, these computerised batteries are specifically designed for widespread use, offering more cost- and time-effective neurocognitive screening (Kohler, 2004; Maroon et al., 2002). These tests can be administered to many athletes at the same time, and standardised test administration can be self-guided (Collie & Maruff, 2003). Computerised tests have the potential to significantly enhance reliability and sensitivity (Collie and Maruff, 2003). Because computerised screening measures are able to maximise response variability to detect extremely slight cognitive impairment, practice effects are minimised (Collie, Darby et al., 2001; Kohler, 2004; Moser & Scahtz, 2002). Further advantages of computer-based tests include the possibility of internet-based delivery, as well as centralised data storage, analysis and reporting (Collie, Darby, et al., 2001).

Computerised neuropsychological tests have been established as psychometrically equivalent when compared against traditional paper and pencil tests. According to Lovell and Collins (2002), the advantages of computerised neuropsychological screening methods far outweigh the disadvantages. There have been numerous studies conducted to establish the sensitivity of computerised tests (Lovell et al., 2004; Erlanger, Feldman, et al., 2003; Collins, Iverson, Lovell et al., 2003; Iverson, Lovell et al. 2003). Computer-administered screening allows for precise measurement of cognitive processes such as reaction time and processing speed, optimising validity and sensitivity to subtle neurocognitive impairment (Iverson, Lovell, & Collins, 2002; Lovell and Collins, 2002). Computer-based assessments are considered to be especially sensitive to subtle changes in attention, concentration, and response latency, and have been found to provide more accurate measurement of reaction time and other general performance measures than examiner-based testing (Schatz & Zillmer, 2003).

Computerised neuropsychological tests such as CogSport, developed in Australia, and Concussion Resolution Index (CRI, Headminder) and Immediate Post-concussion Assessment and Cognitive Testing (ImPACT), developed in the United States, are concussion software products marketed to sports professionals who are responsible for the management of concussed players (Schnirring, 2001).

CogSport: CogSport was developed in 1999 by CogState, a university-affiliated research institute in Melbourne, to monitor MTBI recovery in professional and semi-professional Australian football clubs (Collie, Maruff et al., 2003). The test battery, which takes approximately 15 minutes to administer, uses playing cards as stimuli with almost infinite equivalent alternate forms (Makdissi et al., 2001). The CogSport programme generates measures for cognitive domains of simple and complex attention, working memory, short-term memory and new learning, incidental memory, adaptive problem solving, continuous performance, and spatial abilities (Makdissi et al., 2001; Schatz & Zillmer, 2003). Results are submitted to CogState in Australia for scoring and assessment, with optional features including "customised reports, custom data for import into popular statistical packages, assistance in interpretation of results for publication or presentation, assistance in the preparation of research protocols or IRB submissions, storage and retrieval of data and results, and mirroring of stored data for increased security" (Schatz & Zillmer, 2003, p.44).

Studies pertaining to the reliability of CogSport have recognised the programme as a highly reliable test of cognitive function, particularly in the domains of psychomotor functioning, decision-making, working memory and learning (Collie et al., 2003c). Validation studies have been conducted with approximately 300 professional Australian Football players with associated noninjured controls. Good test-retest coefficients and external validation with Trail Making and Digit Symbol Substitution Tests have been established (Collie, Darby et al., 2001; Schatz & Zillmer, 2003). A high correlation between some measures of CogSport and traditional paper and pencil neuropsychological tests tapping information processing speed and attention has been established (Collie et al., 2003).

Concussion Resolution Index (CRI): The Concussion Resolution Index (CRI), developed by the New-York based HeadMinder Institute, is a web-based computerised test battery which provides online neuropsychological assessment tools for sports professionals responsible for the management of concussion (Erlanger, Saliba, et al., 2001). Administration of the CRI takes place preseason, and then at various stages postinjury. This programme is currently in use by a number of professional, semi-professional, club, college and high school organisations in many countries (Erlanger, Feldman, et al., 2003). The CRI takes approximately 25 minutes to administer, and comprises demographic details, medical and concussion history, and self-report symptoms, as well as six subtests tapping visual memory, reaction time, decision making and information processing speed (Erlanger et al., 2001; Schatz & Zillmer, 2003). The CRI evaluates self-report symptoms postinjury and monitors the resolution of these symptoms. Test results from the CRI are scored online and the results made available to the on-site test administrator whose responsibility it is to interpret scores and provide feedback to the athlete.

The CRI has been established as a valid and reliable cognitive performance measure (Erlanger, Feldman, et al., 2003). According to Erlanger, Saliba, et al. (2001), current studies suggest that the CRI is sensitive to postconcussive sequelae in athletes. Studies have indicated strong concurrent validation between CRI subtests of reaction time and decision-making and Symbol Digit Modalities Test, WAIS-III Digit Symbol and Symbol Search, Grooved Pegboard, and Trail Making Tests (Erlanger et al., 2003). Studies suggest that the CRI is sensitive to postconcussive symptoms, and incorporates an internal symptom validity measure to identify possible chance responding or significantly impaired baseline test performance (Erlanger et al., 2003).

Thus, both CogSport and the CRI have been established as valid and reliable screening instruments in the assessment of postconcussive sequelae. Key differences between the two measures are: (i) that while the CRI makes use of traditional neuropsychological tests, CogSport utilises unusual stimuli in the form of playing cards; and (ii) the CRI includes a self-report symptom scale while CogSport focuses only on neurocognitive assessment with no symptom checklist. A disadvantage of both of these computerised testing systems is their web-based analysis which may limit in-depth analysis of scores based on demographic details, thereby restricting research possibilities.

ImPACT: The ImPACT test incorporates the advantages of good reliability and validity, a more comprehensive traditional neuropsychological test battery, and a symptom checklist, and generates psychometric data for on-site analysis by trained clinicians. Designed by the University of Pittsburgh Medical Centre Sports Medicine

Concussion Programme to resolve some of the limitations of traditional paper and pencil tests (Lovell & Collins, 2002), ImPACT and has been widely implemented in baseline and postinjury screening at amateur and professional levels of sports participation (Lovell & Collins, 2002; Schatz & Zillmer, 2003). ImPACT offers a wide-ranging neurocognitive test battery and utilises a novel approach which simultaneously taps multiple cognitive skills (Lovell and Collins, 2002). The programme comprises seven test modules: attention, verbal and visual memory, processing speed, and reaction time to 1/1000th of a second (Maroon et al., 2000). ImPACT also contains a demographic questionnaire and a 21-item symptom checklist (Collins, Iverson, et al., 2003), and takes approximately 20 minutes to administer (Lovell & Collins, 2002). Recently, an updated version of ImPACT (version 3.0) was introduced which distinguishes between visual and verbal memory, rather than the composite memory score offered by the earlier version 2.0. This aspect sets ImPACT apart from the CogSport and CRI test batteries which do not assess verbal memory.

Baseline data for over 5000 athletes, and concussion data on approximately 340 athletes, has been gathered on ImPACT (Schatz & Zillmer, 2003). Preliminary studies on the psychometric properties of ImPACT indicate strong validity and reliability (Maroon, Field, et al., 2002). Reliability is enhanced due to the objective evaluation of cognitive processes, doing away with potential scoring faults resulting from human bias or error (Lovell & Collins, 2002). All data obtained is stored on a computer, allowing for easy accessibility and the capability to store extensive databases for research purposes (Lovell, 2002). ImPACT test scores are presented in such a manner as to facilitate comparison between baseline scores and postinjury performance (Maroon, Field, et al., 2002). Accurate, efficient clinical assessment of individual athletes is promoted through the computer-generated composite indices that allow isolation of particular domains of cognitive impairment (Lovell & Collins, 2002). Unlike the CogSport and CRI test systems which submit data for analysis elsewhere, ImPACT test scores are generated for interpretation by appropriately trained, on-site neuropsychologists, enhancing research possibilities.

In a study to determine the stability of ImPACT (Version 2.0), test scores and the calculation of reliable change confidence intervals for the test-retest coefficients were assessed (Iverson, Lovell, et al., 2003). Test-retest coefficients for the five composite scores provided by ImPACT are considered equivalent or better than other traditional neuropsychological tests. With regard to the reliable change parameters, considerable change between performance scores preseason to postconcussion in Verbal Memory, reaction time, and self-reported symptoms were identified, and a moderate to considerable difference in visual memory and processing speed (Iverson et al., 2003). These preseason to postconcussion effect sizes are analogous to other tests in other populations. Iverson, Lovell et al. (2003) assert that a large percentage of athletes show substantial changes in functioning in the first few days postinjury and that this reflects the sensitivity of the computerised test battery to acute effects of concussion (Iverson, Lovell, et al., 2003). This particular study established a "very short" test-retest interval, thereby limiting the external validity. The authors caution that "the reliable change difference scores are meant to supplement, not replace, clinical judgement" (Iverson, Lovell, et al., 2003, p. 466).

In a study conducted by Iverson, Lovell, and Collins (2005) to assess the construct validity of ImPACT, computerised test scores were compared to those obtained by using a traditional neuropsychological test, Symbol Digit Modalities Test (SDMT) which has been extensively used in concussion research to assess scanning and tracking aspects of attention and speed of processing. According to the authors "it appears as if the Processing Speed Composite, Reaction Time Composite, and SDMT are measuring a similar underlying construct in this sample of concussed amateur athletes" (p.2). ImPACT appears to be the only computer-based neuropsychological testing programme that has been used to investigate the cumulative effects of sports-related concussion (Iverson, Lovell, Collins, & Norwig, 2002). Findings indicate that the memory composite score (in Version 2.0), and the post-concussive symptom checklist items associated with concentration and memory, were sensitive to memory deficits related to multiple concussions (Iverson, Lovell, Collins, Norwig, 2002).

ImPACT has been substituted for the previously used paper and pencil tests administered on various professional teams including the Pittsburgh Steelers and the Philadelphia Eagles (Maroon et al., 2002). However, Lovell and Collins (2002) express concern that despite the improved ease of administration and evaluation afforded by computerised methods, there has been limited implementation of these screening methods at high school and college level. This is disappointing due to the large numbers of at-risk athletes at these levels. Additional studies are needed to assess the construct validity of ImPACT against paper and pencil tests that have proven their effectiveness in the assessment of diffuse brain damage. Notably successful tests include Digit Symbol, Trail Making Test Parts A and B and Digits Backward (Lezak et al., 2004). Trail Making Test Parts A and B, and Digits Backward were amongst those tests able to distinguish between cognitive deficits among rugby and non-rugby players in studies conducted by Shuttleworth-Edwards et al. (2004).

Computer-based neuropsychological research has focused predominantly upon American Football and soccer players (Lovell & Collins, 2002). To date, Rugby Union studies conducted in South Africa have investigated chronic concussive sequelae using paper and pencil tests and have indicated that cognitive impairment is more pronounced in rugby players than in non-contact sports players (Shuttleworth-Edwards et al., 2004). These studies have highlighted deficits in delayed verbal and non-verbal memory, verbal attention, information processing speed and memory. Age, degree of exposure to contact due to position of play, and previous cognitive difficulties were found to further contribute to postconcussive symptomatology (Shuttleworth-Edwards et al., 2004).

1.3.3. Management issues relating to MTBI

The appropriate management of MTBI in athletics is a contentious and challenging area of sports medicine and there is discrepancy and confusion with regard to treatment and return to play decisions (Collins, Grindel, et al., 1999). The lack of clear, well-established management guidelines pertaining to sports-related MTBI is disturbing and potentially dangerous (Collie et al, 2001). A 1995 study by Genaurdi and King (cited in Moser & Schatz, 2002) revealed that hospital discharge instructions for youth athletes with concussion were appropriate for only 30.3% of the Grade 1 concussions, 20.0% of the Grade 2 concussions, and for none of the Grade 3 concussions.

Appropriate identification and management of concussion entails a multidisciplinary approach involving medical and athletic professionals (Wojtys et al., 1999; Barr, 2003). The on-field diagnosis and assessment of concussions may be problematic due to the wide discrepancy of presenting symptoms and many coaches, athletic trainers and sports physicians may lack the necessary knowledge to diagnose a MTBI, especially when cognitive difficulties are involved (Lovell & Collins, 1998). Although signs of cognitive decline and/or reported postconcussive symptoms constitute evidence of acute MTBI (Lovell, Collins, et al., 2003), in the absence of obvious signs and symptoms of concussion (for instance, loss of consciousness, posttraumatic amnesia, nausea and vomiting, and balance difficulties), more understated symptoms may remain undetected by the athlete or the coach. A confounding issue, which is particularly common at the professional sporting level, involves the reluctance of athletes to report postconcussive symptoms to avoid being removed from play (Leclerc et al., 2001; Lovell & Collins, 1998). As discussed previously, premature return to play following a concussion puts the athlete at risk of cumulative brain injury and SIS (Cantu, 2001).

Recovery rates have been shown to vary significantly between individuals (King, 2003; Leclerc et al., 2001; McCrory & Johnston, 2002). Despite this, sport organisations have employed broad, and sometimes ambiguous, guidelines to the management of MTBI which often entail rigid obligatory suspension periods from play depending on the evaluation of the injury severity (Kohler, 2004). Until recently, International Rugby Board regulations required that any concussed player be excluded from active competition for a period of three weeks (Marshall & Spencer, 2001). McCrory (2001b) asserts that the lack of empirically valid guidelines for return to play decisions makes it very difficult for sports medicine practitioners to make a scientifically-based medical decision, and as such may leave doctors vulnerable to medico-legal problems, especially at the professional level. In this regard it is essential that the return to play decision is not an arbitrary one, due to its wide-ranging consequences on the athlete's career, financial status, and physical and psychological well-being (Echemendia & Cantu, 2003), but rather based upon an individualised assessment of clinical and neuropsychological recovery (Maroon et al., 2000; McCrory, 2001b).

Recommendations pertaining to sports concussion management arising from the Vienna Conference (Aubry et al., 2002) included the proposed implementation of a systematic management protocol of MTBI in sports (Kohler, 2004). The Concussion in Sport Group (CISG) proposed the implementation of a conservative management approach to concussion injuries in athletes involving postinjury medical evaluation and subsequent assessment to facilitate a carefully-monitored, gradual and safe return to play process (Aubry et al., 2002). This conservative approach was extended through the management guidelines proposed by the Prague Conference (McCrory et al., 2005). Following these guidelines, an athlete with any sign or symptom of concussion should not return to the current game or practice and should undergo medical evaluation and progressive monitoring, with return to play taking place only once all symptoms have resolved (McCrory et al., 2005).

Guidelines arising from both the Vienna and Prague conferences recognise the role of neuropsychological assessment as a cornerstone of concussion management. The Vienna Conference emphasises the importance of baseline preinjury testing and serial postconcussive follow-up (Aubry et al., 2002). Computerised screening tools (such as ImPACT) are acknowledged as potentially reliable, valid and useful instruments in this regard (Aubry et al., 2002). As discussed earlier, the more recent Prague conference's differentiation between simple and complex concussions is a contentious development, and one which informs concussion management. Simple concussions, which are expected to resolve within a few days postinjury, involve medical evaluation and a stepwise progression to return to play (McCrory et al., 2005). Prague Conference recommendations for complex concussions (which would include athletes with a history of multiple concussions) outline a more cautious and prolonged process of return to play, managed by multidisciplinary teams including a specialised physician (McCrory et al., 2005). In contrast to recommendations of the Vienna Conference, Prague Conference guidelines posit that neuropsychological testing is indicated for complex concussions only. The nature and depth of this assessment, however, requires elucidation. Prague Conference recommendations do not specify whether brief neuropsychological screening, in the form of isolated traditional paper and pencil tests or the more sophisticated computerised concussion screening tools (such as ImPACT), or more probing testing is warranted. Although not elucidated by McCrory et al. (2005), an in-depth, traditional neuropsychological test battery for complex concussions may be warranted that serves to augment a screening battery, the nature of which will be discussed below.

1.3.3.1. In-depth neuropsychological testing

In-depth neuropsychological assessment batteries are utilised with two chief purposes: (i) to provide diagnostic accuracy, and (ii) the functional assessment of individuals with known neurological difficulties (Lezak et al., 2004). Ideally, a neuropsychological test battery of this type consists of standardised and normed tests with established validity and reliability, facilitating the detection and quantification of neurocognitive impairment (Mitrushina, Boone, & D'Elia, 1999). Typically, the cognitive domains which are assessed include verbal comprehension, attention and concentration, visuospatial perception, executive functioning, motor function, and verbal and non-verbal learning and memory (Stringer & Nadolne, 2000). Performance on an isolated test is not sufficient for the detection of brain dysfunction, and it is emphasised that interpretation should be informed by the pattern of test performance within each functional domain (Mitrushina et al., 1999). The utility of the neuropsychological test battery is extended and strengthened by a qualitative component which is informed by the clinical judgement of the neuropsychologist (Mitrushina et al., 1999).

Deficit measurement approach in neuropsychological testing: This approach to neuropsychological assessment involves the intraindividual comparison of an individual's abilities, skills and level of functioning (Lezak et al., 2004) and is founded on the assumption that there is an "ideal, normal, or prior level of functioning against which the patient's performance may be measured" (Lezak et al., 2004, p. 88). Information regarding the individual being assessed, the particular behaviour being evaluated, and the reason for the assessment are factors which determine whether performance is compared against a normative range or an individual level of functioning.

The deficit measurement approach entails the determination of deficits against a comparison of assumptions of premorbid abilities and skills, inferred from demographic data and previous test performance (Lezak et al., 2004). Estimations of premorbid intellectual functioning may be based on a variety of sources including: (i) the highest subtest score on a test of general intellectual functioning (such as the WAIS-III), or the highest level of functioning in everyday tasks; (ii) performance on a cluster of WAIS-III subtests known to remain intact in association with diffuse neuropathological conditions, including MTBI; (iii) tests of well-learned, familiar skills such as reading where correlations with intelligence have been established; and (iv) the use of actuarial methods using data pertaining to age, sex, race, education, and occupation (Spreen & Strauss, 1998).

Fundamental assumptions underlying this approach are that the level of best performance achieved (for example, the highest test score or highest indication of premorbid achievement) should be regarded as the most accurate estimate of premorbid ability, and that under normal circumstances, there is a single performance level that most accurately represents an individual's cognitive skills and abilities across all functional modalities (Lezak et al., 2004). Apparent fluctuations or patterns of cognitive deficit, detected through the comparison of the individual's present level of functioning against the comparison standard, are evaluated for statistical significance to determine actual areas of neurocognitive impairment (Lezak et al., 2004). Patterns of functional impairment are then interpreted in relation to expected patterns of neuropsychological impairment for a particular condition, in order to provide diagnostic clarity pertaining to the particular individual (Lezak et al., 2004).

Following the principles of the deficit measurement approach of Lezak et al., (2004), the in-depth neuropsychological test battery for this study was chosen to facilitate the estimation of the premorbid level of intellectual functioning. Furthermore, due to the individualised presentation of neurocognitive deficit patterns following MTBI, additional neuropsychological tests were selected which are both sensitive to possible subtle impairment following brain injury, and which are able to assess the multiple cognitive domains which may be affected by MTBI. As discussed previously, prior studies have shown neurocognitive impairment following MTBI to affect a variety of functional domains, namely information processing speed, working memory, visual and verbal memory, verbal fluency, and hand/motor speed and dexterity (Killam et al., 2005; Lovell & Collins, 1998; Randolph, 2001).

Accordingly, the in-depth neuropsychological test battery incorporated the Wechsler Adult Intelligence Scale (WAIS) III battery (Wechsler, 1997a) of general intellectual functioning. Two WAIS-III subtests, namely Picture Completion and Vocabulary, are considered to be resilient to the effects of brain injury, and are thus reliable indicators of premorbid ability (Lezak et al., 2004), while the test battery provides a multidimensional assessment of various cognitive functions. Expected findings related to performance on the WAIS-III following MTBI might include impaired functioning on the Performance subtests relative to the Verbal subtests, reflecting sensitivity to timed mental processing abilities assessed by the performance subtests. Similarly, the WAIS-III Processing Speed Index and the Working Memory Index may reflect particular cognitive vulnerabilities in these domains resulting from diffuse brain damage caused by concussion. Subtests which assess information processing speed, working memory, verbal memory and motor functioning (such as Digit Symbol Coding, Letter-Number Sequencing, Arithmetic, Block Design, and Matrix Reasoning) might be expected to reflect impairment (Lezak et al., 2004).

Further, the Wechsler Memory Scale (WMS) III (Wechsler, 1997b) was administered as part of the in-depth neuropsychological test battery to assess verbal and visual memory functioning. It is anticipated that impairment in these areas, reflected by WMS-III delayed and immediate auditory and visual index scores might be evident in an individual with neurocognitive sequelae following MTBI. In addition, the WMS-III Working Memory Index may indicate neurocognitive difficulties.

Additional tests incorporated in the more probing test battery include hand and motor tests, namely the Finger Tapping Test (Denckla, as described in Hemp, 1989) and the Purdue Pegboard Test (Tiffin, 1968) to possibly highlight indications of motor slowing. Two verbal fluency tasks, namely the unstructured Words-in-a-minute Test (as described by Hemp, 1989) and the COWAT Verbal Fluency Test (Benton, Hamsher, & Sivan, 1994) were administered to assess possible impairment with verbal initiation, a known difficulty following MTBI. The Rey Complex Figure Test (Osterrieth as described in Lezak et al., 2004) copy task was administered; this untimed visuoperceptual test has shown varying efficacy in its sensitivity to deficits on executive functioning following MTBI (Lezak et al., 2004). Anticipated findings in this study might be that aspects pertaining to planning and organisation on this task may show impairment. Additional visual memory tests, in the form of the Rey Complex Figure Test (Immediate and Delayed Recall) (Lezak et al., 2004) and the Digit Symbol Coding Incidental Recall Test, an extension of the WAIS-III subtest, were administered to reveal possible lowered performance levels in respect of visual memory.

1.4 Rationale for this study

Much of the published research conducted to this point in the field of sports-related MTBI appears to have been focused on groups using quantitative multivariate analysis. As indicated above, on the basis of an extensive literature review on PUBMED and PsychInfo, there do not appear to be case-based studies pertaining to neuropsychological recovery following sports concussion. Although multivariate methods allow for the control and measurement of variables, there are limitations with regard to their ability to examine unique features of individual cases (Edwards, 1998). In contrast, case-based research offers an empirical method of systematically analysing the context and "complexity of the real-life situation" (p.590) by combining a case narrative with quantitative methods (Edwards, Dattilio, & Bromley, 2004). Case-based strategies offer the potential of a systematic focus on individual nuances relating to MTBI presentation, recovery and return to play, and research findings in this area would serve to augment, and possibly refine, aspects of existing studies.

Thus, as part of a larger group study investigating computer-based assessment of University top-team rugby players, it was decided to conduct an in-depth study of a single case of a 20 year old concussed rugby player with a history of multiple concussions. ImPACT 3.0 computer-based screening, together with two traditional paper and pencil tests known to be sensitive to the diffuse effects of MTBI, namely WAIS-III Digit Span and Trail Making Test Parts A and B, were administered in the acute follow-up phase, and a more extensive neuropsychological battery was carried out postseason, including WAIS-III, WMS-III, Finger Tapping Test, Purdue Pegboard Test, Words-in-a-minute test, COWAT Verbal Fluency Test, Rey Complex Figure (copy, immediate and delayed recall), and the WAIS-III Digit Symbol Incidental Recall Test.

Specific research questions of the study were as follows: (i) to examine the recovery curve following MTBI in the acute phase following concussion in an individual with high BRC on ImPACT 3.0 and two paper and pencil tests known to be sensitive to cognitive impairment following MTBI; and (ii) to identify whether subtle indications of persistent impairment following multiple concussions on the ImPACT neurocognitive screening battery would be ratified with the more probing traditional neuropsychological assessment.

CHAPTER 2: METHODOLOGY

2.1. Participant

2.1.1. Selection

The participant, XY, upon whom this case study is based, is a first team rugby player, who was initially part of a larger group-based study on rugby players taking place at Rhodes University. Together with the rest of the Rhodes University first team rugby players, XY underwent preseason baseline testing. On 12 March 2005, XY was concussed during a rugby game and referred for postconcussion assessment. Accordingly, he was excluded from the group study that focused on chronic effects of concussion, and became available for further analysis in the present study.

The diagnosis of concussion was made informally by the coach on the basis that XY had been punched on the right temporal region of his skull by a player from the opposition. Although he tried to resume play, XY immediately experienced disorientation and confusion which continued for approximately 15 minutes. No loss of consciousness or post-traumatic amnesia were reported. In terms of the commonly applied severity classification scales, XY's concussion would be categorised as a grade 1 concussion according to the Cantu and Colorado guidelines, and as a mild concussion following American Academy of Neurology guidelines (Bailes & Hudson, 2001) (refer to earlier discussion pertaining to concussion classification in Chapter 1, p.3).

During the pre-season baseline testing XY reported having sustained at least 4 prior concussions. In light of this history of multiple concussions, he was selected as a candidate for in-depth neuropsychological assessment. XY's identifying data appear below in Table 2.1.

Table 2.1. Identifying Data for XY

Pseudonym	XY
Date of birth	30/05/1985
Age	19
Current Sport	Rugby Union
Team at time of concussion	Rhodes University A or B
Primary position	Flank
Date of concussion	12/03/2005
Number of previous concussions	4+
Psychiatric history	None
Medical history	None

2.2. Initial neurocognitive screening measures

2.2.1. Preseason questionnaire

This questionnaire, in a paper and pencil format, comprises questions pertaining to demographic information, concussion history, and medical and psychiatric history (see Appendix A).

2.2.2. WAIS-III Digit Span and Trail Making Test Parts A and B

These paper and pencil tests have been found to be sensitive to neurocognitive deficits following MTBI.

2.2.2.1. WAIS-III Digit Span

The WAIS-III Digit Span subtest forms one of the 11 subtests of the WAIS-III test battery (Wechsler, 1997a). The score from the subtest contributes toward the Verbal IQ score (Wechsler, 1997a). The subtest comprises Digits Forward and Digits Backward components, both tasks consisting of seven pairs of fixed, random digit sequences (Groth-Marnat, Gallagher, Hale, & Kaplan, 2000). The Digits Forward task requires the examinee to repeat the series of digits, read by the examiner, as they increase in length. The Digits Backwards task requires that the fixed random numbers are repeated by the examinee in reverse order (Groth-Marnat et al., 2000). The scores of these tasks reflect the number of series repeated correctly on each subtest. The Digits Forward and Backward Span scores reflect the highest span of digits repeated correctly (Groth-Marnat et al., 2000).

The WAIS-III Digit Span assesses auditory attention, concentration, immediate verbal recall, and short-term retention capacity (Groth-Marnat et al., 2000; Lezak et al., 2004). It has been included in a variety of studies assessing the neurocognitive recovery of athletes post-MTBI (Barr, 2003; Barth et al., 1989; Collins et al., 1999; Grindel, et al., 2001). The Digits Forward test, chiefly a measure of attention, is more likely to be sensitive to left hemisphere damage than to right hemisphere or diffuse damage (Lezak et al., 2004). A study conducted by Matser et al. (cited in Lezak et al., 2004) on soccer players has shown the test to be sensitive to impairment following multiple concussions.

The Digits Backwards test assesses an individual's ability to apply cognitive double-tracking in performing the memory and digit reversing operations simultaneously, and is thought to entail a verbal and visual component (Lezak et al., 2004). This test is sensitive to TBI, with impaired test performance possibly suggesting difficulties with left hemisphere damage visual field defects (Lezak et al., 2004) or left frontal/parietal/temporal injuries (Golden, Espe-Pfeifer, & Wachsler-Felder, 2000). A study conducted by Guskiewicz, Ross, and Marshall (2001) found the Digits Backwards test a particularly sensitive measure for tracking recovery following concussion in athletes.

For the purposes of this study, this subtest was administered individually to XY by the researcher, according to the standardised WAIS-III administration procedures (Wechsler, 1997a).

2.2.2.2. Trail Making Test

The Trail Making Test, originally a component of the Army Individual Test Battery, has been included in the Halstead-Reitan battery (Spreeen & Strauss, 1998). It is an easily administered test which has two parts (Lezak et al., 2004) and the two scores obtained from this test reflect the total time in seconds taken to complete Part A and

Part B (Mitrushina et al., 1999). Part A requires the examinee to draw a continuous line between circles containing numbers 1 to 25, located at fixed, random positions on a page, as fast as they can. On Part B, the examinee is instructed to connect fixed, random circles containing both numbers and letters in such a way that they alternate (ie. 1 is followed by A, which is followed by 2 and B etc.) (Spreen & Strauss, 1998).

Trail Making Test Part A assesses simple cognitive processing speed and visuomotor tracking (Broshek & Barth, 2000), whereas Part B taps complex information processing speed and cognitive flexibility. Part B is sensitive to cognitive inflexibility, and has been shown to correlate with Working Memory Indices of WAIS-III and WMS-III (Broshek & Barth, 2000). The Trail Making Test is "highly vulnerable" to neurocognitive dysfunction with the severity of TBI associated with slowed performance on both Parts A and B (Lezak et al., 2004, p. 372; Spreen & Strauss, 1998). Guskiewicz et al. (2001) assert that Trail Making Test Part B is a useful test for postconcussion assessment due to its sensitivity to memory and concentration impairment.

It is important to note that the Trail Making Test is susceptible to practice effects (Lezak et al., 2004). Studies have shown Part A to be particularly vulnerable to practice effects, while performance on Part B has demonstrated large group variances (Lezak et al., 2004; Spreen & Strauss, 1998).

For the purposes of this study, the Trail Making Test was administered individually to XY by the researcher according to Reitan's standardised procedure (as outlined in Spreen & Strauss, 1998).

2.2.2.3. Immediate Postconcussion Assessment and Cognitive Testing (ImPACT) (Version 3.0)

As discussed in the Chapter 1 (p. 24), ImPACT is a computer-based neuropsychological screening package which includes a demographic questionnaire and a symptom checklist. Computer-based testing allows for simultaneous assessment of a number of athletes at the same time (Lovell, 2002), and is administered by clinical neuropsychologists, certified athletic trainers, or physicians (Iverson et al., 2003).

The test battery comprises seven individual modules that evaluate neurocognitive functions vulnerable to MTBI. ImPACT converts these modules into five composite scores: Verbal Memory (made up of a word recognition test, a symbol-number match task, and a letter memory task), Visual Memory (comprising an abstract figure memory task and a task requiring the identification of highlighted X's and O's), Processing Speed (representing "the weighted average of three tasks that are done as interference tasks for the memory paradigms" (p. 461)), Reaction Time ("the average response time on a choice reaction time, go/no-go task" (p. 461), and the symbol match task) and Impulse Control (Iverson et al., 2005). The Impulse Control composite score is still undergoing reliability and validation testing, and thus will not be included in this study (Iverson, Lovell et al., 2003).

The composite scores generated by ImPACT can be compared against approximate classification ranges corresponding with particular ages and/or educational levels based on US normative data. Normative classification ranges for university men, based on a sample of 410 individuals, are depicted below in Table 2.2.

Table 2.2. Estimated classification ranges for composite scores for university men (ImPACT 3.0 Manual, 2004)

	Verbal Memory	Visual Memory	Processing Speed	Reaction Time
Impaired	<71	<51	<23.8	>.75
Borderline	72 – 77	52 – 60	23.9 - 28.3	.74 - .67
Low average	78 – 82	61 – 68	28.4 – 32.4	.66 - .61
Average	83 – 94	69 – 94	32.5 – 42.0	.60 - .52
High average	95 – 97	95 – 97	42.1 – 46.0	.51 - .48
Superior	98 – 99	98 – 99	46.1 – 50.0	.47 - .45
Very superior	100	100	>50.1	<.44

The ImPACT postconcussion symptom scale assesses 22 commonly experienced symptoms which are graded according to severity (0 – 6) and a total symptom score is computed (Iverson et al., 2003). The US normative postconcussion symptom classification scale for university men is as follows: raw symptom score of 0 represents 'low to normal' range; 1 – 5 is classified as 'normal'; 6 – 12 is classified as 'unusual'; 13 – 20 is classified as 'high'; and a symptom score greater than 21 is classified as 'very high' (ImPACT Normative Data, 2002).

The ImPACT Clinical report is generated by the computer and provides a summary of relevant biographical information and details pertaining to the individual's medical and psychiatric history. ImPACT presents the neuropsychological test performance on each of the six composite scores is reflected as individual's percent correct on individual's performance and the associated age-related percentile. In addition, a graphic representation of the individual's performance across various cognitive domains enables comparison of performance at different testing intervals (ImPACT 3.0 Clinical Interpretation Manual, 2004). The symptoms reported by the athlete are also indicated on the report.

Reliable Change Indices (RCIs) have been determined to facilitate a more accurate understanding of changes in ImPACT composite scores which may suggest neurocognitive deterioration, improvement and recovery (Iverson et al., 2003). A study to determine test-retest coefficients for the five composite scores suggested "seemingly relatively modest" stability coefficients (Iverson et al., 2003, p. 464). Compared against other established neuropsychological test measures, however, the ImPACT composite score stability coefficients are comparable or superior. As a result of practice effects noted on the Processing Speed Composite, appropriate changes were made to the relevant RCIs. Practice effects were not noted on the other tests (Iverson et al., 2003). It is important to note, however, that the randomised multiple versions of ImPACT tasks are designed to reduce practice effects

The ImPACT testing took place in an individual setting where there were no disturbances. Administration followed the procedure specified by the ImPACT 3.0 Manual (2004), and test results generated by ImPACT were printed and stored on computer.

2.3. Postseason in-depth neuropsychological test battery

2.3.1. Rationale for test selection

As discussed previously in Chapter 1 (p. 30), following the principles of the deficit measurement method of Lezak et al. (2004), tests selected for the study were chosen according to their ability to assess general intellectual ability and particular domains of neurocognitive functioning known to be vulnerable to MTBI. Tests with established reliability and validity were favoured.

2.3.2. General intellectual functioning

2.3.2.1. Wechsler Adult Intelligence Scale (WAIS) III

The WAIS-III (Wechsler, 1997a) is an instrument providing individualised, multidimensional neuropsychological assessment (Groth-Marnat et al., 2000). The battery comprises 14 subtests which assess various aspects of cognitive functioning along finely graded levels of difficulty. Standardised individual test norms permit comparison of performance on different subtests. A Full Scale IQ (FSIQ) score, considered a good indicator of academic achievement, is derived from the sum of Scaled Scores from 11 subtests, some verbal- and others performance-oriented. The verbal subtests include: Vocabulary, Similarities, Arithmetic, Digit Span, Information, Comprehension, Letter-Number Sequencing; the performance subtests comprise: Picture Completion, Digit Symbol Coding, Block Design. Matrix Reasoning, Picture Arrangement, Symbol Search, Object Assembly. Based on performance on these subtests, a Verbal IQ (VIQ) and Performance IQ (PIQ) score is calculated. In addition, Index Scores relating to Verbal Comprehension, Perceptual Organisation, Working Memory and Processing Speed, are computed from formal factor indices (Lezak et al., 2004).

As discussed previously (Chapter 1, p. 31), performance on the Vocabulary and Picture Completion subtests are considered reliable indicators of premorbid functioning (Lezak et al., 2004).

In this study, the WAIS-III test battery was administered by the researcher in an individual setting according to the standardised procedure (Wechsler, 1997a). Subtests were scored and interpreted by the researcher, and scoring was verified by a co-researcher.

2.3.3. Memory functioning

2.3.3.1. Wechsler Memory Scale (WMS) III

The WMS-III (Wechsler, 1997b) is a widely used neuropsychological battery assessing various components of memory and generating eight primary memory indices, namely: Auditory Immediate; Visual Immediate; Immediate Memory; Auditory Delayed; Visual Delayed; Auditory Recognition Delayed; General Memory; and Working Memory (Lezak et al., 2004). This test battery allows for the identification of relative strengths and weaknesses in the memory process based on the following subtests: Logical Memory, Faces, Letter-Number Sequencing, Digit Span, Spatial Span, Verbal Paired Associates, Family Pictures, Words Lists, and Visual Reproduction (Lezak et al., 2004). An advantage of the WMS-III is the co-norming with the WAIS-III by means of "a sample of individuals in the standardisation samples being shared across the two instruments" (Franzen & Iverson, 2000, p.210). This standardisation of the WAIS-III and WMS-III allows for direct comparison of performances across tests from both batteries.

A number of the WMS-III measures, such as Immediate and Delayed Auditory Indexes, Immediate Memory, Visual Delayed Index, and General Memory, are considered to be more sensitive to neurocognitive effects of MTBI than WAIS-III summary scores (Franzen & Iverson, 2000; Lezak et al., 2004) and measures of internal consistency and stability on the WMS-III are considered superior to those on the WAIS-III (Franzen & Iverson, 2000).

For the purposes of this study, the researcher followed the standard administration procedures in administering and scoring the WMS-III (Wechsler, 1997b). A co-researcher verified the scoring.

2.3.4. Additional tests

In addition to the WAIS-III and WMS-III which incorporate assessment of many functional modalities, additional paper and pencil tests were administered.

2.3.4.1. Hand/motor dexterity tests

Finger Tapping Test: The Finger Tapping Test (as described in Hemp, 1989) is a timed test, administered on the preferred and non-preferred hand. The examinee's speed in sequentially touching each finger to the thumb on five consecutive continuous trials is recorded in seconds.

Motor slowing and coordination difficulties are commonly experienced following MTBI (Lezak, et al., 2004). The results of this test allow finger speed and dexterity to be evaluated against age-specific norms. In this study, the test was administered by the researcher to XY according to the procedure outlined by Denckla (as described in Hemp, 1989).

Purdue Pegboard: The Purdue Pegboard (Tiffin, 1968) was developed in the 1940s as a test of manual dexterity to inform employment selection (Spreen & Strauss, 1998). The test involves a number of motor tasks requiring the manipulation of metallic pins, washers and collars along two parallel rows of holes, using the preferred and non-preferred hand. The first task requires the examinee to take the pins in his right hand and place the pin the right hand row as fast as possible in a 30-second period. The same procedure is repeated with the left hand using the left row of holes. The following task requires the examinee to use both hands to put pins into both rows as fast as he can in a 30-second period. After these pins are counted, they are removed. The assembly trial involves the construction of pins, washers and collars using alternating hands during a 60-second period. Demonstration and practice are allowed prior to each trial. Scoring entails the counting of the number of pins correctly placed in the preferred, non-preferred and both hands trials, and the total number of pins, washers and collars on the assembly task. This test assesses manual dexterity and fine motor control, functions that may be impaired following MTBI (Golden et al., 2000; Lezak et al., 2004). Administration of the test in this study followed standardised procedure as outlined in the Purdue Pegboard manual (Tiffin, 1968). XY was tested in an individual setting.

2.3.4.2. Verbal fluency

Words-in-a-minute: The Words-in-a-minute test (as described by Hemp, 1989) requires the individual to produce as many different words as possible in one minute. The score reflects the number of permissible words (proper nouns and variations of the same word are not allowed) generated in one minute. TBI may impair the speed and ease of verbal initiation (Lezak, et al., 2004). Verbal fluency is dependent upon efficient organisation of verbal retrieval and recall. The verbal fluency tests assess cognitive flexibility, short-term memory, the "ability to initiate and maintain word production set" (p.132), and the capacity to inhibit response (Mitrushina et al, 1999). Performance on this test may provide insight to possible frontal lobe difficulties in areas of executive functioning such as flexibility, inhibition, and perseveration, as well the ability to apply strategies for the word generation (Golden et al., 2000). Variations of this test have been incorporated into a number of studies assessing neurocognitive recovery following sports concussion (Grindel et al., 2001; Lovell & Collins, 1998). In this study, standardised administration procedures (as described in Hemp, 1989) were followed by the researcher, and XY was tested in an individual setting.

Controlled Oral Word Association Test (COWAT): The COWA test (Benton et al., 1994) of verbal fluency, carried out in three parts, requires the examinee to produce as many words beginning with the letters F, A and S as possible. Scoring reflects the number of appropriate words stated on each of these tests. Differences between the unstructured (the Words-in-a-minute test described above) and a structured verbal fluency task may suggest difficulties with verbal initiation dependent on the level of organisation within the task. The standardised administration and scoring procedures for the F-A-S Words-in-a-minute were followed (Benton et al., 1994).

2.3.4.3. Visuoperceptual untimed test

Rey Complex Figure (Copy task): The Rey Complex Figure (Osterrieth, 1944) comprises a complex two-dimensional line drawing with 18 associated geometric components. The copy task is untimed, and requires the examinee to copy the figure exactly as it is presented. The client's reproductions are evaluated and scored according to the presence and accurate placement of identified elements. Various scoring systems have been utilised, although the most commonly used one is that proposed by Osterrieth, and adopted by Taylor (in Spreen & Strauss, 1998) in which the 18 elements are assigned a score from 0.5 to 2.0 according to accuracy, location and distortion of the copy. In addition, the strategy and organisation employed for the undertaking of the task may be qualitatively analysed (Mitrushina et al., 1999). Seven strategies for the completion of the copy task were identified by Osterrieth (in Lezak et al., 2004) which have been statistically linked with various neuropathological conditions.

The copy task of the Rey Complex Figure assesses executive processes such as planning, organisational skills, and visuoperceptual and visuomotor abilities (Lezak et al., 2004; Selby, 2000). According to Lezak et al. (2004), TBI may have varying effects on an individual's performance on this task, with only one third of individuals with brain damage performing at a significantly low range relative to the norm.

For the purposes of this study, the Rey Complex Figure test was administered by the researcher in an individual setting according to standard procedure (as outlined in Spreen & Strauss, 1998). Scoring was conducted according to the Rey-Osterrieth/Taylor method (as described in Lezak et al., 2004) and verified by a co-researcher.

2.3.4.4. Visual memory tests

Rey Complex Figure (Immediate and delayed recall): The Rey Complex Figure (Osterrieth, 1944) immediate and delayed recall tasks involve the prompting of the examinee for reproduction of the complex figure copied previously in the test battery (Lezak et al., 2004). For the immediate recall task of the Rey Complex Figure test, the examinee is requested, without forewarning, to reproduce the figure as best as they can from memory immediately following the copy task (Mitrushina et al., 1999). The delayed recall task is administered approximately 30 minutes following the immediate recall task, and the examinee is again asked to reproduce the complex figure as best they can. There is no time limit for the immediate and delayed tasks (Spreen & Strauss, 1998).

These recall tasks assess visual memory, visuospatial functioning, and verbal learning (Stringer & Nadolne, 2000). In this study, the Rey Complex Figure immediate and delayed memory tasks were administered according to the standardised method outlined by Lezak et al. (2004).

WAIS-III Digit Symbol Coding (Incidental recall): The WAIS-III Digit Symbol Coding test (Wechsler, 1997a) is one of the 11 subtests which make up the WAIS-III test battery of general intellectual functioning. The test comprises rows of empty blocks with random numbers (1-9) associated with each block. For the copy task, the examinee is instructed to use the key at the top of the page, in which the digits 1 through 9 are paired with corresponding symbols, to visually pair and transcribe the appropriate symbols in the empty blocks. Following a practice trial, the examinee is instructed to complete as many sequential blocks as possible in 120 seconds.

The Incidental Recall test is an extension of Copy task and requires the examinee to recall and record the symbols that match with the numbers 1 through 9.

The incidental recall task assesses visual short-term working memory. Because memory is vulnerable to diffuse brain injury, the recall task is considered highly sensitive to brain damage (Lezak et al., 2004; Shuttleworth-Jordan & Bode, 1995) and has been utilised in postconcussion neurocognitive test batteries (Grindel et al., 2001).

In this study the incidental recall task was administered to XY by the researcher according to the standardised methods of the WAIS-III (Wechsler, 1997a) in an individual setting.

2.4. Procedures

2.4.1. Preseason

2.4.1.1. Orientation

An informational talk was delivered by the present researcher and co-researchers to members of the University A and B rugby teams. The talk addressed issues pertaining to the identification and management of concussion and the use of neuropsychological testing in making safe return-to-play decisions. Athletes were told about the research and asked for their voluntary participation in the study. Following the talk, athletes were issued with consent and withdrawal forms and the pre-season questionnaire. All rugby players, including XY, the participant who is the focus of the case study, signed the voluntary consent forms; no withdrawals were received.

2.4.1.2. Administration of tests

Testing was conducted by the researcher and co-researchers who were trained in and familiar with the administration procedures and protocols of relevant neuropsychological test instruments. Pre-season testing included individual administration of WAIS-III Digit Span and Trail Making Test Parts A and B. In addition, all rugby players, including XY, the participant, were tested on Impact 3.0 to obtain a preseason baseline.

2.4.2. Postconcussion testing

The researcher was informed by the coach that the participant, XY, had sustained a concussion. XY underwent post-concussion assessment on ImPACT 3.0, WAIS-III Digit Span, and Trail Making Test Parts A and B approximately 36 hours following the concussion, and at weekly intervals for three weeks until the XY's performance had reached (and surpassed) his baseline scores and postconcussion symptoms were reported to have resolved.

2.4.3. Postseason testing

Postseason testing was conducted individually on all rugby players enlisted in the study, including XY. The Digits Forwards and Backwards test, Trail Making Test Parts A and B, and ImPACT 3.0 were administered. The in-depth neuropsychological test battery was administered individually on XY according to standardised administration procedures and comprised: WAIS-III, WMS-III, Finger Tapping Test, Purdue Pegboard Test, Words-in-a-minute test, COWAT, Rey Complex Figure (Copy and Immediate and Delayed Recall), and WAIS-III Digit Symbol Incidental Recall test. Scoring was verified by a co-researcher, trained in the appropriate test administration and scoring procedures.

2.5. Data Analysis

The pre-season baseline score, as well as the US normative scale for the individual's age group, was descriptively compared with the scores obtained during the post-concussive assessment. Analysis of cognitive functioning on the ImPACT 3.0 test was descriptively compared with an analysis of function on the full neuropsychological battery using the deficit measurement approach of Lezak et al (2004), as described in Chapter 1 (p. 30).

CHAPTER 3: CASE STUDY

3.1. Concussion history

3.1.1. Present concussion

XY was concussed on Saturday 12 March 2005, during a rugby game in which he was playing in the position of flank. While lying on the ground after a tackle, he was punched on the right temporal region of his skull by a player from the opposition. XY reported that he immediately stood up and tried to resume play, however, realised within about 30 seconds, that he was confused and disoriented. This alteration of mental state continued for about 15 minutes after receiving the blow to his head. No loss of consciousness or amnesia was reported. He subsequently left the rugby field and did not return to play. XY was wearing a mouthguard at the time of the injury. No first aid was administered, nor did XY take any medication for any symptoms of his concussion. At the first postconcussive testing session two days following the concussion, XY seemed vague and uncertain regarding his experience of any other symptoms at the time of the concussion. His description of the events surrounding the injury seemed to be reliant on others' accounts of the incident. He consulted a General Practitioner on 14 March 2005 who confirmed the concussion.

3.1.2. Prior Concussions

XY has had four previous concussions in 1994, 1996, 2000, and 2001, two of these occurring during rugby games. XY reports that he experienced a loss of consciousness for ten minutes following the concussion in 2000, and that he experienced confusion and memory difficulties pertaining to events before and immediately after the injury on all of these occasions. In addition to these concussions, XY reported that he has experienced a number of other incidents, while playing rugby, in which he received a blow to the head and experienced subsequent feelings of being dazed or "shaky", although he was unable to quantify these incidents. XY was unable to recall additional specific symptoms on any of these other occasions. A summary of XY's past and present concussion history appears below in Table 3.1.

Table 3.1. Summary of XY's concussion history, including current concussion, and experience of loss of consciousness, and symptoms of confusion and memory difficulties for events immediately after and prior to the injury.

Concussion	Year	Reason	LOC (Duration)	Confusion	Memory difficulties for events after injury	Memory difficulties for events before injury
1	1994	Rugby – XY ran into a tackle	No	Yes	Yes	Yes
2	1996	Bicycle accident	Yes (10 min)	Yes	Approx. 30 minutes	Approx. 30 minutes
3	2000	Fall during high jump	No	Yes	Yes	Yes
4	2001	Rugby tackle	No	Yes	Yes	Yes
5	2005	Rugby	No	Yes	Yes	Yes

3.2. Other relevant history

3.2.1. Family

XY's parents and an older sibling are first class academics at a tertiary level.

3.2.2. Medical

XY reported that he has not experienced any medical problems. When he was 7 years old he had chicken pox. He reported that his maternal grandfather and grandmother both had cancer.

3.2.3. Psychiatric

None reported.

3.2.4. Sports

XY reported that he has always enjoyed a variety of sports. He started to play rugby in primary school, and continued at high school where he played for the first team. While at high school he also participated in swimming, tennis, athletics, waterpolo, and basketball.

3.2.4. Education

XY entered Grade 1 at the age of 6 years, and stayed at the school until Grade 7. He reported achieving "mostly A's" throughout each standard of primary school. XY's high school education was undertaken at a private school. Due to his enjoyment of sports, he reports that he did not put a lot of time or effort into his schoolwork. Despite this, he achieved good marks, mostly ranging from As to Cs. XY's favourite subject was History, while he found Mathematics the most challenging. While at school, XY demonstrated clear leadership abilities. XY's achieved the following Matric marks: English – B; Afrikaans – B; Mathematics – D; History – A; Business Economics – C; Physical Science – C. All subjects were taken on Higher Grade.

XY is currently in his first year of a Bachelor of Arts degree. He was in the second month of his first year studies when he sustained his most recent concussion.

Based on XY's family background and his educational history, his premorbid level of intellectual functioning is postulated to fall in at least the high average to superior range.

3.3. Initial neurocognitive screening measures

3.3.1. Administration

Baseline testing was conducted on 09/03/2005. The first postconcussion neuropsychological assessment took place approximately 48 hours after the injury on 14/03/2005. Subsequent postconcussive testing was conducted on 23/03/2005 and 29/03/2005, and postseason testing on 28/09/2005.

3.3.2. Clinical observations

During the first postconcussion testing session XY, complained of difficulties with concentration, feeling "slowed down" and "mentally foggy". At the second postconcussion session he reported symptoms of drowsiness and memory difficulties. During the third postconcussion assessment session, XY reported a headache, slight dizziness and nausea.

3.3.3. *Test results*

3.3.3.1. ImPACT 3.0 test results

These test results appear in Table 2.

Table 3.2. Summary of ImPACT test results for baseline test, three postconcussion tests, and postseason testing in comparison with the US normative data for male University students in the average range.

	Preseason Baseline	Postconc 1	Postconc 2	Postconc 3	Post-season	US Norm Average Range
Date tested	09/03/2005	14/03/2005	23/03/2005	29/03/2005	28/09/2005	
Last Concussion	30/05/2002	12/03/2005	12/03/2005	12/03/2005	12/03/2005	
Composite Scores						
Verbal Memory	77_{10}*	83_{24}	79_{15}	85_{35}	95_{80}	83-94
Visual Memory	78_{52}	69_{25}	83_{66}	81_{59}	73_{36}	69-94
Visual-motor speed	35.23_{39}	**27.25_{7}**	39.95_{65}	49.70_{96}	38.35_{56}	32.5-42.0
Reaction time	0.55_{49}	0.58_{33}	0.52_{68}	0.51_{71}	0.55_{48}	0.60 – 0.52
Impulse Control	4	5	3	3	6	

* denotes percentile rank according to ImPACT US norms for university men
Scores in bold type indicate scores that exceed the US Reliable Change Index (RCI) score when compared with the baseline score.

It is evident that XY's preseason baseline performance on all composites was within or below the average range (25th – 75th percentile), except for Verbal Memory which falls within the borderline range (refer to ranges described in Chapter 2, p. 38). On the first postconcussive testing session, the only composite score to reflect a significant drop in functioning was the Visual-Motor Speed index. XY's Visual-Motor Speed performance dropped to the borderline level, significantly below his low average baseline score, exceeding the Reliable Change Index. This decline suggests deleterious cognitive effects due to the concussion. This score, however, improved during the second and third postconcussive assessments to exceed the baseline score. Specifically, on the third postconcussive testing, XY attained a

Visual-Motor Speed score which falls in the 96th percentile (superior range), but this drops down in the postseason testing session to the average range of the 56th percentile. However, both these scores are better than XY's baseline performance, suggesting recovery from the concussion.

The fluctuations evident on XY's Visual-Motor Speed composite are similarly evident on the Verbal Memory composite which falls in the 10^{th} percentile (within the borderline range) at preseason, but then fluctuates between average (24^{th} percentile), low average (15^{th} percentile), average (35^{th} percentile) and high average (80^{th} percentile) levels of functioning on the subsequent testing sessions.

Table 3.3. Self-reported postconcussive symptoms on the ImPACT Symptom Scale at baseline, at the postconcussive assessment, and at postseason. (with increasing sensitivity rating from 0 – 6)

	Preseason	Postconc. 1	Postconc. 2	Postconc. 3	Postseason
Date of test	09/03/2005	14/03/2005	23/03/2005	29/03/2005	28/09/2005
Physical symptoms	Headache (2); Dizziness (1); Fatigue (1); Sleeping more than usual (2); Drowsiness (2); Sensitivity to noise (1)	Nausea (3); Dizziness (3); Fatigue (3); Sleeping more than usual (2); Drowsiness (3);	Fatigue (1); Sleeping more than usual (1); Drowsiness (1); Sensitivity to noise (1)	Fatigue (1); Sleeping more than usual (1); Drowsiness (1); Sensitivity to noise (1)	Fatigue (1); Trouble falling asleep (1); Sleeping more than usual (1); drowsiness (1); sensitivity to noise (1)
Cognitive symptoms	Feeling slowed down (2); Feeling mentally foggy (1); Difficulty concentrating (1); Difficulty remembering (1)	Feeling slowed down (3); Feeling mentally foggy (5); Difficulty concentrating (5); Difficulty remembering (4)	Feeling mentally foggy (1); Difficulty concentrating (1); Difficulty remembering (1)	Feeling mentally foggy (1); Difficulty concentrating (1); Difficulty remembering (1)	Feeling slowed down (1); feeling mentally foggy (1)
Emotional symptoms	Irritability (2);	Irritability (2)	Irritability (1)		Irritability (1); nervousness (1)
Total score US	16	**33**	8	7	9
Normative category*	High	Very High	Unusual	Unusual	Unusual

Scores in bold denote significantly high number of postconcussive symptoms
* Average US norm for university men: 1 - 5

XY's self-report of symptoms at preseason, postconcussion, and postseason testing reflects an experience of symptoms which is consistently above the US norm (refer to description of US normative categories, p. 51).

During the pre-season assessment, XY reported a symptom score of 16. On the first postconcussive follow-up he scored 33, a significant increase of 17 symptoms over the baseline score, which is suggestive of a concussive injury and noted the following symptoms: nausea, dizziness, fatigue, drowsiness, feeling slowed down and mentally foggy, difficulty concentrating and poor memory. On the second and third post-concussion testing sessions XY indicated lower symptom scores of 8 and 7 respectively, more closely approaching the US norm (which ranges between 1-5) and below that of his baseline score, suggesting recovery from the concussion.

3.3.3.2. Trail Making Test

The results of XY's performance on Part A and Part B of the Trail Making Test appear in Table 3.4. below.

Table 3.4. Results of Trail Making Test Parts A and B

	Baseline	**Post Conc. 1**	**Post Conc. 2**	**Post Conc. 3**	**Postseason**	**Norms[1] (SD)**
Date of test	09/03/2005	14/03/2005	23/03/2005	29/03/2005	28/09/2005	
Part A	20.15	31.94	16.42	19.27	13.85	23.8 (6.81)
Part B	59.46	33.90	35.78	29.78	37.32	53.9 (18.31)

[1]Mitrushina, Boone, & D'Elia, 1999, Handbook for Normative Data for Neuropsychological Assessment (Males, Education beyond High School, Age 20 – 39)

XY's performance in the first postconcussive testing session indicates a slower performance on Part A of the Trail Making test when compared to his level of preseason functioning. This decline in performance could be attributed to the concussion. Compared to age-appropriate norms, XY's baseline performance, is marginally better than the norm, and dropped considerably to a performance level below the norm on the first postconcussion testing session. The scores on Part A of the Trail Making test during the second and third postconcussive testing sessions indicate a return to XY's baseline level of functioning, and suggest recovery from the concussive injury. XY's preseason performance on Part B is slightly slower than the norm (but within one standard deviation). The first postconcussive testing session score reflects a significant improvement in performance, as the time taken to complete the task is faster than the norm (and greater than one standard deviation from the norm).

3.3.3.3. WAIS-III Digit Span

XY's scores from the Digit Span test are presented in Table 3.5.

Table 3.5. Results of WAIS-III – Digit Span

	Baseline	**Post Conc. 1**	**Post Conc. 2**	**Post Conc. 3**	**Postseason**	**Norm[1] (SD)**
Date of test	09/03/2005	14/03/2005	23/03/2005	29/03/2005	28/09/2005	
Digits forward	11	12	12	12	12	
Digits backward	10	7	8	10	10	
Digits forward Span	7	7	8	9	7	7.54 (1.51)
Digits backward Span	7	5	5	6	7	6.00 (1.44)
Digits difference	0	2	3	3	0	1.57 (1.59)

[1]Shuttleworth-Jordan (1991), English-speaking university students, aged 18 – 25

Baseline scores for the Digits Forwards and Backwards Spans indicate average functioning in the area of immediate verbal recall. XY's performance on the Digits Backwards subtest during the first and second postconcussive testing, however, suggests slightly impaired verbal working memory relative to XY's baseline scores. This decline in performance suggests deleterious neurocognitive effects as a result of the concussion. His performance during the third postconcussive testing session, however, indicates a return to baseline functioning and recovery from the concussion.

3.4. Postseason in-depth neuropsychological test battery

3.4.1. Administration

The first testing session took place on 1 October 2005, and involved the administration of the WAIIS-III. The WMS-III and additional cognitive tests were administered during the second session on 9 October 2005.

3.4.2. Clinical observations

XY arrived on time for both testing sessions. On the second testing session he remarked that he was feeling very tired as he had not slept well the previous night, but declined the offer to reschedule the testing session. XY participated willingly during the testing sessions. He appeared calm and confident during the verbal-oriented tasks, and these tasks did not seem to require much effort. Some of the visuoperceptual tasks, especially those requiring a motor component (such as WAIS-III Block Design and Object Assembly subtests), seemed to be more challenging for XY as he took time manipulating and constructing objects. It was during these tasks that his motivation and concentration seemed to fluctuate, and his fatigue seemed more apparent.

3.4.3. Test results

3.4.3.1. General Intellectual Functioning

Wechsler Adult Intelligence Scale Third Edition (WAIS-III^{UK})

The results from the WAIS-III are shown on Table 3.6.

Table 3.6. Age-adjusted Scale Scores on the WAIS-III

WAIS-III	**Scale Score**	**Intellectual functioning**
VERBAL SUBTESTS		
Vocabulary	19	
Similarities	16	
Arithmetic	14	
Digit Span	15	
Information	15	
Comprehension	14	
Letter-Number Sequencing	(13)	
PERFORMANCE SUBTESTS		
Picture Completion	13	
Digit Symbol Coding	11	
Block Design	13	
Matrix reasoning	13	
Picture Arrangement	10	
Symbol Search	(11)	
Object Assembly	(10)	
INDEX SCORES		
Full Scale IQ (FSIQ)	129	Superior
Verbal IQ (VIQ)	138	Very Superior
Performance IQ (PIQ)	113	High Average
Verbal Comprehension (VCI)	140	Very Superior
Perceptual Organisation (POI)	118	High Average
Processing Speed (PSI)	106	Average
Working Memory (WMI)	124	Superior

Table 3.7. Discrepancy Analysis for WAIS-III Indices

Discrepancy Comparisons	**Score 1**	**Score 2**	**Difference**	**Statistical Significance 0.05 level**
Verbal IQ – Performance IQ	138	113	25	**9.07**
Verbal Comprehension – Perceptual Organisation	140	118	22	**9.71**
Verbal Comprehension – Working Memory	140	124	16	**9.90**
Perceptual Organisation – Processing Speed	118	106	12	13.29
Verbal Comprehension – Processing Speed	140	106	34	**12.69**
Perceptual Organisation – Working Memory	118	124	-6	10.75
Working Memory – Processing Speed	124	106	18	**13.43**

Scores in bold type indicate statistically significant discrepancy

The Full Scale IQ is considered a reliable and valid estimation of general academic ability and work performance, however this score should be interpreted cautiously if there is a significant difference between the Verbal and Performance IQs (Groth-Marnat et al., 2000). XY's Verbal IQ is 25 points higher than Performance IQ, representing a statistically significant difference, with the implication that FSIQ score should not be used as a baseline of general intellectual abilities. Golden et al. (2000) recommend that VIQ and PIQ (or preferably, VCIQ and POIQ) should be used as alternative reference point for verbal and nonverbal functioning in this situation. XY's VIQ score reflects a very superior level of functioning on tasks measuring verbal ability such as abstract reasoning, verbal fluency, and verbal memory. The VIQ also links strongly with XY's level of tertiary education.

The significantly lower Performance IQ compared with the Verbal IQ may suggest difficulties with practical and/or timed tasks, information processing difficulties, psychomotor slowing, and/or impaired visuomotor speed.

Similarly, XY's Index Scores indicate statistically significant variation (Table 3.7) ranging from the Verbal Comprehension Index (VCI) which indicates a very superior level of functioning, to the Processing Speed Index (PSI) which falls in the average range. Like the VIQ, the very superior VCI score indicates XY's strengths with regard to verbal memory, verbal fluency and verbal reasoning. The Perceptual Organisation Index (POI) measuring nonverbal, fluid reasoning, attention to detail, and visual-motor integration (Groth-Marnat et al., 2000) falls within the high average range of functioning. XY's score on the Working Memory Index (WMI) suggests abilities related to short-term memory, concentration, attention and the ability to work with numbers (Groth-Marnat et al., 2000) lie in the superior range. It is noteworthy, that the subtests which comprise the WAIS-III WMI (namely Arithmetic, Digit Span, and Letter-Number Sequencing) have a strong verbal component. The PSI, which assesses motor functioning, memory, planning and organisation, falls at an average level of functioning, significantly below the VCI.

3.4.3.2. General Memory Functioning

Wechsler Memory Scale – Third Edition (WMS-III)

Scores obtained on the WMS-III are reflected in Table 3.8 and Table 3.9 below.

Table 3.8. WMS-III Index scores with associated percentile ranking and description of memory functioning

Index	Score	Percentile	Qualitative description
Auditory Immediate	127	96	Superior
Visual Immediate	127	96	Superior
Immediate Memory	134	99	Very Superior
Auditory Delayed	114	82	High Average
Visual Delayed	122	93	Superior
Auditory Recognition Delayed	120	91	Superior
General Memory	124	95	Superior
Working Memory	105	63	Average

Table 3.9. WMS-III Ability-Memory Differences

Primary Indexes	WAIS-III IQ Score	Memory Index Score		Predicted Ability-Memory Difference Score	Statistical Significance 0.05 level
		Predicted	Actual		
Auditory Immediate	129	117	127	-10	16.2
Visual Immediate	129	110	127	-17	16.8
Immediate Memory	129	117	134	-17	16.3
Auditory Delayed	129	117	114	3	14.2
Visual Delayed	129	112	122	-10	15.7
Auditory Recognition Delayed	129	114	114	0	14.2
General Memory	129	117	124	-7	15.2
Working Memory	129	120	105	15	**13.9**

Scores in bold denote statistically significant differences

XY's Index Scores reflect a range of memory functioning from the very superior to the average level. The Immediate Memory score, which falls in the very superior range, is suggestive of relative strengths in the ability to encode new verbal auditory information. The General Memory Index comprises delayed performance only and falls in the superior range. This index score is considered to be more sensitive to neurological impairment than Immediate or Working Memory. The Working Memory composite measures attention and immediate working memory processes, and should be less affected by brain injury than the other composite scores (Golden et al., 2000). According to Golden et al. (2000), this score should fall within 15 points of General Memory. In XY's case, however, Working Memory score is 19 points lower than General Memory, possibly suggesting emotional or motivational difficulties. The WMS-III Working Memory Index is considered comparable with the WAIS-III Working Memory Index (Golden et al., 2000). As discussed previously, the WAIS-III WMI is comprised of Arithmetic, Digit Span and Letter-Number Sequencing subtests incorporate a verbally-oriented working memory. In contrast, the WMS-III WMI, made up of Letter-Number Sequencing and Spatial Span subtests, has a stronger visual memory component. XY's superior performance on the WAIS-III WMI against his average WMS-III WMI performance might suggest short-term visuospatial retention difficulties.

3.4.3.3. Additional Paper and Pencil Tests

Scores from the additional paper and pencil tests administered are reflected below in Table 3.10.

Table 3.10. Scores from additional tests

Additional Tests	Score	Norms	SD
FINGER TAPPING TEST			
Preferred Hand (Right)	4.95	5.17[1]	0.68
		4.85[2]	1.23
Non-preferred Hand	5.98	5.19[1]	0.70
		5.07[2]	1.17
PURDUE PEGBOARD TEST			
Preferred Hand (Right)	14	15.56[3]	1.52
		15.44[4]	1.71
Non-preferred Hand	14	15.09[3]	1.42
		15.08[4]	1.98
Both hands	9	12.59[3]	1.56
		12.97[4]	1.18
Assemblies	32	40.25[3]	4.64
		38.89[4]	6.60
WORDS-IN-A-MINUTE			
Unstructured	44	49.5[5]	
		52[6]	
"F" words	19	13.82[7]	4.36
		4.99[8]	4.37
"A" words	21	12.48[7]	3.87
		13.33[8]	4.89
"S" words	17	15.87[7]	4.52
		16.63[8]	4.97
REY COMPLEX FIGURE			
Copy Trial	35	35.1[9]	1.5
Immediate Recall	21.5		
Delayed Recall	21.5	22.7[10]	7
Osterrieth Strategy	II		
DIGIT SYMBOL			
Incidental Recall	7	7.32[11]	1.68

[1]Shuttleworth-Jordan & Bode (1992) Rhodes University (English-speaking, age 20 - 39)
[2]Shuttleworth-Jordan (1992) Rhodes University (English-speaking, age 18 – 25)
[3]Spreen & Strauss (1991) Boys (Age 15 – 20)
[4]Spreen & Strauss (1991) Boys (age 21 – 25)
[5]Shuttleworth-Jordan (1992) Rhodes University (English-speaking, age 18 – 25)
[6]Shuttleworth-Jordan (1995) (English-speaking, age 18 – 25)
[7]Yeudall et al. (1986) (Age 15 – 20)
[8]Yeudall et al. (1986) (Age 21 – 25)
[9]Spreen & Strauss (1991) (age 16 – 30)
[10]Kolb & Whishaw (1985) (Age 16 – 30)
[11]Shuttleworth-Jordan (1995) (English-speaking, university students, age 18 – 25)

Hand/motor dexterity tests

Finger Tapping Test: XY's preferred hand performance falls within the age-appropriate norms. Although his non-preferred hand performance is slightly slower than the 20 – 39 year old university norms, this speed falls within one standard deviation of the norms for university students aged 18 – 25. There is, therefore, no suggestion of bilateral slowing.

Purdue Pegboard Test: XY's performance on the preferred and non-preferred hand tasks indicates motor speed and fine motor control which falls within the average range of functioning as his scores on these tasks fall within one deviation of age-appropriate norms. There is no difference between the performance of his preferred and non-preferred hand. On the task involving both hands, however, XY's score falls two standard deviations below the norm. Similarly, on the assemblies task his performance falls two standard deviations below the norm. Thus, XY's performance on these tasks might suggest difficulties with motor speed and dexterity as the task becomes more complicated.

Verbal fluency tests

Unstructured Words-in-a-minute Test: XY's performance on the unstructured part of this test falls below the norm. This might suggest below average verbal fluency abilities, especially when the task lacks structure, and difficulties with organisation.

COWAT Verbal Fluency Test: XY's performance on the more structured verbal fluency tasks falls within or above the age-appropriate norms. It is possible that the unstructured task, which was administered prior to the structured task, allowed him the opportunity to "practice" word generation, and that the additional structure provided by the F-A-S word task facilitated his ability to list words. On a qualitative level, XY initially listed common noun words, mostly words naming objects within the testing room. However, this strategy seemed to change gradually as he undertook the "F", "A", and "S" tasks as noted in his increasing usage of more abstract words such as "federal, fjord, fraternity, apex, asymmetric, subdued, surreptitious, surreal". XY's ability to generate words, therefore, appears to be good, although his speed is perhaps hampered by a tendency to "intellectualise" or overperform on the task.

Visuoperceptual untimed test

Rey Complex Figure (Copy task): The Copy component of the Rey Complex Figure test assesses planning and perceptual organisational ability. XY's score falls within the norm for his age group, suggesting intact visuomotor and visuospatial skills. His use of the Osterrieth Strategy Type II is fitting with the majority (83%) of individuals (and 63% of the TBI group) in Osterrieth's sample (as cited in Lezak et al, 2000).

Visual memory tests

Rey Complex Figure test (Immediate and Delayed recall): The Immediate and Delayed components of the Rey Complex Figure test are designed to measure immediate and short-term visuoperceptual memory. XY's performance falls within the normal range of functioning. However, he did not seem particularly motivated on these recall tasks, which might also be linked to fatigue.

Digit Symbol Incidental Recall: XY's performance on this test falls within the normal range of functioning, suggesting average visual memory abilities.

CHAPTER 4: DISCUSSION

4.1. Rationale for this study

This study set out to conduct an in-depth investigation of the neuropsychological profile of a rugby player with an estimated premorbid level of intellectual functioning in at least the high average to superior range and a history of multiple concussions. A case study method was adopted, whereas prior research on the cumulative effects of sports concussion has tended to be conducted on groups using quantitative, multivariate analysis. It was envisaged that a case-based approach would facilitate a detailed focus on individualised details surrounding sports-related concussion, and potentially enhance existing knowledge pertaining to the presentation, recovery and management of MTBI. The following research questions were the focus of this study: (i) to examine the recovery curve in the acute phase postconcussion in an individual with postulated at least high average to superior premorbid functioning on IMPACT 3.0, a computerised neurocognitive and symptom screening programme, and WAIS-III Digit Span and Trail Making Test, two paper and pencil tests known to be sensitive to deleterious neurocognitive effects of concussion; and (ii) to investigate whether the subtle indications of persistent neurocognitive impairment on ImPACT 3.0, using US normative data, in an individual with estimated relatively high premorbid functioning and a history of multiple concussions, would be verified using a more probing traditional neuropsychological assessment.

4.2. Interpretation of test findings

4.2.1. Initial neurocognitive and symptom screening measures

The diagnosis and management of concussion is a challenging area of sports medicine due to the wide variation in the presentation of postconcussive neurocognitive sequelae and symptoms, which may often remain undetected due to their subtle nature (Marshall & Spencer, 2001). This is confounded by the tendency for athletes to underreport symptoms (Leclerc et al., 2001). Neurocognitive deficits which have been associated with MTBI include information processing speed, memory, attention, verbal fluency, working memory and executive functioning (Killam et al., 2005; Lovell & Collins, 1998). Neuropsychological assessment has been increasingly used as a sensitive measure in the detection of neurocognitive deficits following concussion (Maroon et al., 2000) and recently, computerised neuropsychological screening measures, such as ImPACT, have been developed to enhance assessment of the concussive injury and management of the recovery process (Schatz & Zillmer, 2003; Schnirring, 2001). In this study, the neuropsychological postconcussion recovery curve was investigated through the administration of ImPACT 3.0, WAIS-III Digit Span and the Trail Making Test. These neurocognitive and symptom screening tests were administered preseason to obtain a baseline score, and on four postconcussion testing sessions.

Baseline assessment across all these initial screening measures suggests that XY is functioning on these tests at an average to low average level. This is in contrast with his postulated premorbid level of functioning, which, based on his personal and family history, is estimated to be in at least the high average to superior range. There are various possible reasons for this discrepancy. Firstly, it is possible that the lower than expected baseline scores are the result of chance or situational factors such as feeling particularly fatigued, in that at this test interval, XY does report a cluster of symptoms relating to fatigue, namely sleeping more than usual, drowsiness, and feeling slowed down. However, XY did not note any difficulties while undertaking this testing session when prompted to complete the ImPACT 3.0 "comments" section, and he reported having had 8 hours of sleep on the night prior to testing. Secondly, the US normative data which are used on ImPACT 3.0 and the Trail Making Test may not be applicable to XY's South African developmental and educational background, although XY's high level of functioning and advantaged educational background increase the likely equivalence between his performance and the US normative data. A third possibility may be that XY's baseline performance is suggestive of persistent deficits following his multiple concussions. This is in accordance with a study conducted by Collins, Grindel, Lovell et al. (1999) that found lowered neurocognitive performance on college football athletes with a history of multiple concussions, and another of Moser and Schatz (2002) who similarly found decreased overall cognitive dysfunction in youth athletes (aged 14 –

19 years) who had sustained more than two concussions.

With regard to the first postconcussive testing session, the ImPACT 3.0 Visual Motor Speed composite showed significant impairment relative to XY's baseline level of functioning. Similarly, performance on the Trail Making Test Part A, pointed to deficits relating to visual motor speed. The WAIS-III Digits Backward span reflected impairment when compared with XY's preseason performance, an indication of difficulties with verbal working memory. Together, these indications of deleterious neurocognitive effects suggest the presence of concussive injury. This is to be expected, given that processing speed is a function which is particularly sensitive to diffuse brain damage (Echemendia & Julian, 2001; Lezak et al., 2004; Mathias et al., 2004). Similarly, according to Lezak et al. (2004) working memory impairment is sometimes the only discernible neurocognitive deficit following MTBI, and various studies have identified working memory difficulties in athletes with sports-related concussion (Echemendia & Julian, 2001; Lovell & Collins, 1998; Macchiochi et al., 1996).

Athletes who sustain a mild concussion typically exceed their preseason baseline performance on recovery (Lovell et al., 2004). On the second and third postconcussive and postseason testing sessions, XY's performance on each of the ImPACT 3.0 composite scores returns to a level which is at least in the range of, or superior to, his baseline functioning. This would suggest recovery from the acute neurocognitive sequelae detected on the first postconcussive testing session. However, despite the practice offered by the three subsequent postconcussive testing sessions, XY's performance does not reflect the high average to superior level of premorbid functioning expected from his demographic details. Likewise, XY's performance on the three postconcussive testing sessions reflects lower than expected functioning, suggesting possible vulnerabilities with regard to the functional neurocognitive domains assessed by ImPACT 3.0 (namely, verbal memory, visual memory, visual motor speed, reaction time and impulse control), which may be ascribed to his history of cumulative concussions. As indicated earlier, previous studies have determined the presence of neurocognitive impairment in athletes who have a history of more than two concussions (Collins et al., 1999; Moser & Schatz, 2002).

Finally, XY's fluctuating performance on ImPACT 3.0, particularly in respect of the Visual Motor Speed and Verbal Memory composites, is apparent. On the Visual Motor Speed composite, XY's performance, which initially falls in the average range preseason, fluctuates between a borderline, average, superior and average level of functioning on subsequent testing sessions. Similarly, XY's score on the Verbal Memory composite at baseline falls in the borderline range, and then fluctuates between the low average to high average level of functioning. According to Lezak et al., (2004), fluctuations in neuropsychological performance following TBI are relatively common and often indicate difficulties with self-regulation and consistency resulting from executive functioning impairment. Hence, these fluctuations in performance may be a further indicator of areas of neurocognitive vulnerability relative to the estimated premorbid level.

Thus, XY's performance on ImPACT 3.0 on all testing occasions suggests neurocognitive functioning at a range which is lower than expected when contrasted with the estimate of his premorbid ability. This provides a compelling indication of the presence of persistent deficits due to cumulative prior concussions. Further investigation and ratification of these findings would be warranted through the use of an in-depth battery.

In apparent contrast to XY's performance on follow-up testing using ImPACT 3.0, his performance on the Trail Making Test and the WAIS-III Digit Span reflects a different pattern. Whereas ImPACT 3.0 scores reflect a lower than expected performance at baseline and on the subsequent postconcussive testing sessions, XY's scores on the additional paper and pencil screening measures on the second, third and fourth postconcussion testing sessions suggest improvement relative to his preseason performance. Further, the fluctuations in performance on the three postconcussive testing sessions on ImPACT 3.0 are not apparent on the Trail Making Test or Digit Span. This seems to suggest that ImPACT 3.0's multiple alternate versions are more stringent measures of postconcussive neurocognitive vulnerability being less prone to practice effects compared with the known practice effects of the Trail Making Test (Spreen & Strauss, 1998) and Digit Span (Lezak et al., 2004).

Resembling XY's lower than expected ImPACT 3.0 neurocognitive performance at all testing sessions, his self-report of symptoms on ImPACT 3.0 at preseason, postconcussion, and postseason testing reflects an experience of symptoms which is consistently above the US norm. Baseline testing reflects a high symptom score relative to the US norm. This is in accordance with a study conducted by Iverson et al. (2003) where increased baseline symptom reporting was found in individuals with a history of multiple concussions. XY's high baseline symptom score may also be attributed to the presence of postconcussive syndrome which, according to Grindel et al. (2001) is more likely to occur following multiple concussions, and may contribute to an increase in neurobehavioural symptoms.

On the first postconcussion testing session, the symptom score increased by a significant margin to a very high level relative to the US normative data, suggesting the presence of concussion (Bailes & Hudson, 2001; Guskiewicz et al., 2004). Although the symptom scores remain above the average US range, XY's experience of symptoms decreases over the second, third and postseason postconcussive testing sessions as the symptoms resolve to a level which is considerably lower than his preseason score, and only slightly above the US norm. Although the concussed athlete's experience of the resolution of postconcussive symptoms, and improved neurocognitive test performance are not always concomitant (Lovell & Collins, 2002), in XY's case his lowered symptom score appears to be commensurate with the return to at least a baseline level of functioning on the ImPACT 3.0 cognitive tests, suggesting recovery from the acute concussive injury (Maroon et al., 2002).

In sum, on the basis of these initial neurocognitive and symptom screening measures, there are indications of functional areas of deficit which may be the result of cumulative effects from the multiple concussions sustained by XY. According to the Prague Conference concussion management guidelines (McCrory et al., 2005), XY's history of multiple concussions would classify his current injury as a complex concussion which would warrant neuropsychological assessment. As discussed previously, the nature or depth of this assessment is not specified by the authors. However, given the potential diagnostic implications of persistent neurocognitive impairment identified on the initial neurocognitive and symptom screening measures, and the possible bearing that this might have on XY's future participation in contact sports, it is apparent further in-depth neuropsychological assessment would be warranted.

4.2.2. In-depth neuropsychological test battery

In line with the above indications which point to the need for a more probing neuropsychological assessment, an investigation was conducted using the following measures: Wechsler Adult Intelligent Scale (WAIS) III, Wechsler Memory Scale (WMS) III, Finger Tapping Test, Purdue Pegboard Test, Words-in-a-Minute test, Controlled Oral Word Associates Test (COWAT), and Rey Complex Figure test.

As discussed previously (Chapter 1, p. 31), indications of premorbid functioning would best be determined by XY's performance on the WAIS-III Vocabulary and Picture Completion subtests (Lezak et al., 2004). Scaled scores attained by XY on these tests, of 19 and 13 respectively (Table 3.6.), would seem to confirm the initially postulated estimate based on XY's demographic details, that XY's abilities range between the at least high average to superior level of functioning. Further, his performance indicated by a variety of WAIS-III subtests and indices points to neurocognitive strengths. In particular, XY's scores on the WAIS-III Verbal subtests and the Verbal Comprehension Index are suggestive of superior to very superior abilities in these functional domains. In contrast, the scores on the WAIS-III Performance subtests, which incorporate information processing skills and visuospatial functioning (Groth-Marnat et al., 2000), are significantly lower than this, ranging between average and high average. Impairment in this area of functioning is further indicated by the WAIS-III Processing Speed Index, which falls in the average range, a significant drop compared with the superior Working Memory and very superior Verbal Comprehension indices. A significant discrepancy between XY's

WAIS-III performance on the very superior Verbal Comprehension Index and the high average Perceptual Organisation Index further suggests relative difficulties in areas related to visual motor integration and nonverbal reasoning.

Therefore, indications on XY's WAIS-III performance are highly commensurate with those obtained on ImPACT 3.0. In particular, the WAIS-III Performance IQ subtests suggest lower than expected abilities with regard to visual motor processing speed and visuoperceptual skills resembling XY's lower than expected baseline performance on the ImPACT 3.0 cognitive composites of Visual Motor Speed and Reaction Time. Given the extensive use of the WAIS-III for neuropsychological assessment, and established validity and reliability pertaining to the WAIS-III test battery (Spreen & Strauss, 1998), these findings support the presence of deleterious neurocognitive function commensurate with XY's history of multiple concussions. In turn they provide compelling corroboration for similar indications derived on the ImPACT 3.0 test.

With regard to the WMS-III battery, XY's Memory Index Scores range between the very superior to average level of functioning. XY's performance on WMS-III Auditory Memory index scores (immediate, delayed and delayed recognition) ranges between the superior to high average levels. This relatively high level of ability seems to be at variance when compared against XY's baseline performance on the ImPACT 3.0 Verbal Memory composite, which falls in the borderline range. However, as discussed previously, the IMPACT 3.0 Verbal Memory composite is not a purely verbal measure in that it includes the Symbol Matching test as one of its components together with the Word Discrimination and Three Letters tests. Furthermore, unlike the verbal cues administered on the WMS-III, involving auditory recognition and response, the ImPACT 3.0 Verbal Memory composite tasks do not have an auditory component, and visual recognition and motor response to the cue is undertaken by the examinee on the computer. The WMS-III Auditory Memory and the ImPACT 3.0 Verbal Memory composites, therefore, assess different aspects of memory, with the ImPACT 3.0 version showing enhanced sensitivity to concussive sequelae.

The WMS-III Visual Memory index scores (both immediate and delayed) reflect performance in the superior range. This level of functioning appears to be in contrast with the baseline ImPACT 3.0 Visual Memory composite which falls within the average range. However, these differences between XY's performance on WMS-III and baseline ImPACT 3.0 Visual Memory scores can also be attributed in part to the different nature of stimuli used by the different neuropsychological measures. The Visual Memory composite on ImPACT 3.0 comprises the Design Memory subtest, which requires the recognition of abstract, random geometric shapes, and Xs and Os subtests, requiring the identification of the random placement of Xs and Os on a chart. In contrast, the WMS-III Visual Memory Index incorporates immediate and delayed recall for Faces and Family Pictures subtests, and as such, incorporates a strong social element. In XY's case, given his educational background, the social features on the WMS-III Visual Memory tasks are likely to assist with recognition and memory accounting for his superior performance on this test versus only average performance on the ImPACT 3.0 Visual Memory tests, the latter less easily related to social cues. Thus, given the different nature of the two tests which ostensibly test the same cognitive functions, the WMS-III Visual Memory Index would not be expected to necessarily reflect the same areas of relative strength or vulnerability as the ImPACT 3.0 Visual Memory composite score. Again it appears that the ImPACT 3.0 Visual Memory composite (as with the Verbal Memory composite) is a more discriminating marker of residual postconcussive neurocognitive dysfunction than the WMS-III Visual Memory composite.

XY's performance on the WMS-III and WAIS-III Working Memory Indices reflects discrepant levels of ability. The WMS-III Working Memory Index reflects that XY is functioning at an average level, whereas he achieved a superior WAIS-III Working Memory score. A possible reason for this discrepancy may be elucidated by a further level of analysis, suggesting that despite the same names, the indices on the different batteries assess working memory using slightly different cognitive measures. The WMS-III Working Memory Index is comprised of Letter-Number Sequencing and Spatial Span subtests, whereas the WAIS-III Working Memory Index includes Arithmetic, Digit Span, and Letter-Number Sequencing. As such, the WAIS-III

Working Memory Index has an exclusive verbal (auditory) working memory component, against the WMS-III Working Memory Index which is equally weighted for verbal and visual working memory features. It would appear that this visual composite component on the WMS-III Working Memory Index has rendered the test more sensitive to XY's neurocognitive vulnerabilities than the WAIS-III Working Memory Index, and further serves to point to vulnerabilities due to cumulative MTBI.

The further additional measures administered as part of the in-depth test battery assessed hand/motor functioning, verbal fluency, visuoperceptual abilities and visual memory. With regard to XY's performance on the hand/motor dexterity tests, his scores suggest average performance on simple motor tasks. For example, XY's performance on the Finger Tapping task and the preferred and non-preferred hand tasks on the Purdue Pegboard Test indicate functioning which is within the average range. Moreover, increasingly complex tasks, involving visual motor speed and visuoconstructional abilities, such as the both hands and construction tasks on the Purdue Pegboard, suggest low average motor functioning. In accordance with baseline ImPACT 3.0 Visual Motor Speed and Reaction time composites which fall in the average range, and XY's average performance on the WAIS-III Performance subtests measuring processing speed and visuoconstructional abilities, these scores similarly reflect a lower than expected performance relative to XY's level of general intellectual functioning. This finding is expected, given that neuropsychological testing has revealed that motor slowing is the most common impairment evidenced in motor functioning following MTBI (Wrightson & Gronwall, 1999).

With regard to XY's performance on the verbal fluency tasks, scores on the COWAT indicate that XY is able to attain a superior level of verbal fluency when the task is more structured. As noted previously, words initiated by XY on the structured tasks were often abstract and sophisticated, further supporting his superior ability with regard to verbal production, and his high level of education. In contrast, XY's performance on the unstructured Words-in-a-Minute task suggests low average verbal fluency. This is in accordance with Lezak et al.'s (2004) observation that verbal retrieval difficulties are frequently reported by individuals with MTBI, and that verbal retrieval functioning is closely related with slowed speed of information processing. In XY's case, his difficulty in producing words without structured instructions, may suggest vulnerabilities in executive functioning, pointing to frontal lobe involvement (Spreen & Strauss, 1998).

The Rey Complex Figure copy test, an untimed task which has had varying success on patients with TBI (Lezak et al., 2004), was administered to XY as part of the in-depth neuropsychological test battery. His performance on this task is suggestive of intact visuoperceptual abilities and executive functioning. There is no appropriate comparison between performance of this task and any of the ImPACT 3.0 composite scores. XY's performance on the Rey Complex Figure Immediate and Delayed recall tasks reflect average levels of functioning with regard to visual memory. Similarly, his WAIS-III Digit Symbol Incidental Recall score falls within the average range. When compared with XY's premorbid level of intellectual functioning, this visual memory performance would appear to be lower than expected. This finding is in contrast with XY's superior performance on the WMS-III Immediate and Delayed Visual Memory composites, although, as discussed previously, these composites reflect performance on subtests which have predominantly social cues which may aid XY's performance. The lower than expected visual memory performance on the Rey Complex figure and WAIS-III Digit Symbol Incidental Recall, however, which involve geometric designs and symbols (and do not have obvious social associations), is commensurate with XY's average performance on the ImPACT 3.0 Visual memory composite, further supporting the presence of possible persistent cognitive impairments with regard to visual memory functioning.

Thus, overall, the findings from the in-depth neuropsychological assessment battery reveal a compelling level of confirmation in respect of the subtle indications on the initial screening battery, pertaining to relative impairment with speed of visual motor processing, hand/motor dexterity, verbal fluency on unstructured tasks, visual memory and verbal working memory. Findings of impairment in these functional areas are commensurate with those expected in an individual with a history of multiple concussions.

4.3. Overall implications

4.3.1. Neuropathological implications

The pathophysiological processes responsible for neurocognitive impairment following concussion have mostly been derived from in-vivo animal studies, and thus require further clarification in their application to human concussion (Maroon et al., 2002). Recent studies have shown that the acceleration, deceleration, and rotational forces which cause a concussive injury disrupt the autoregulatory process that balances metabolic function with cerebral blood flow giving rise to postconcussive symptoms and neurocognitive impairment (Theye & Muller, 2004). The paucity of human research pertaining to the behavioural phenomenology of concussion, has detrimental implications for sports-concussion management, particularly with regard to cumulative deficits following multiple concussive injuries (Collins et al., 2003).

According to Randolph (2001), the rapid and complete recovery observed in humans who have experienced MTBI of comparable severity to those of animal studies, is most likely attributable to the concept of functional reserve. According to Brain Reserve Capacity (BRC) theory (Satz, 1993), inherent protective factors relating to premorbid features and demographic attributes determine an individual's vulnerability to persistent neuropsychological impairment following MTBI. Neuronal loss resulting from mild traumatic cerebral insult may be compensated for by these factors, such as age, educational level, IQ, although subsequent cerebral insults, however slight, may further deplete this reserve (Satz, 1993). In this regard, a history of previous concussions has been associated with below average neurocognitive performance in executive functioning, information processing, timed word fluency and memory (Collins et al., 1999).

In accordance with BRC theory, it seems probable that XY's history of multiple concussions has resulted in insidious cumulative functional impairment despite an estimated relatively high premorbid level of functioning. In this study, the initial screening tests used to monitor acute postconcussion recovery and the more in-depth traditional neuropsychological test battery support the presence of persistent deleterious neurocognitive effects from multiple concussions. Subtle indications of persistent neurocognitive deficits across the ImPACT 3.0 composites relative to XY's estimated premorbid IQ, are similarly reflected by XY's performance on the WAIS-III which provides further substantiation for the postulated premorbid intellectual functioning at an at least high average to superior level. However, in contrast to this, neurocognitve impairment with regard to processing speed, working memory, and hand/motor dexterity, functional domains known to be sensitive to MTBI, are evident in XY's performance on the initial screening measures and the in-depth neuropsychological test battery. Performance fluctuations, as evidenced on the ImPACT 3.0 Visual Motor Speed and Verbal Memory composites, and on the WAIS-III and WMS-III Working Memory Indices, provide a good demonstration of how the protective threshold of XY's premorbid intelligence and education allow him to maintain some neurocognitive abilities despite cumulative injuries, and to benefit from the practice effects of repeated testing. However, these benefits are not consistently sustained, and fluctuations in performance on the ImPACT 3.0 Visual Motor Speed and Verbal Memory composites are evident.

Thus, in general, as conceptualised in terms of Brain Reserve Capacity Theory, the protective factors of high intelligence and a high level of education have failed to offer protection in XY's case due to additive brain insults, such that clinical signs of deficit have become apparent.

4.3.2. Test implications

Deleterious neurocognitive sequelae which have been attributed to MTBI include information processing speed, memory, attention, executive functioning, verbal fluency and working memory (Randolph, 2001). Normal information processing requires "intact neural structures and functional pathways that subserve a particular cognitive ability" (Mathias et al., 2004, p. 287). As such, the assessment of information processing is suggested by Mathias et al. (2004) as the most sensitive method in the detection of postconcussive neurocognitive impairment

In the initial aspect of this study, the recovery curve following concussion during the acute phase was investigated using a neurocognitive screening battery comprising ImPACT 3.0, the WAIS-III Digit Span and the Trail Making Test, all of which incorporate a strong processing speed component. Accordingly, as anticipated from the literature, the initial neurocognitive and symptom screening measures administered in this study have been shown to be sensitive to acute neurocognitive sequelae following concussion. On ImPACT 3.0, the Visual Motor Speed composite indicated a significant falloff in performance on the first postconcussive testing session relative to the baseline score. Similarly, the Trail Making Test Part A and WAIS-III Digits Backward span scores reflected impairment on the initial postconcussion testing relative to preseason functioning. Performance on these tests on subsequent postconcussion testing sessions indicated improved performance to at least a preseason level of functioning, suggesting recovery from the concussive injury. However, it was of note that the Trail Making Test and WAIS-III Digit Span were more prone to practice effects not having the advantage of the multiple alternate versions offered by ImPACT 3.0. This serves to confirm that the use of these paper and pencil tests in tracking recovery are problematic as they may offer a false impression of resolution of impairment. As has been pointed out by Barr (2003) and Lovell (2002), this has potentially dangerous implications should such tests be used exclusively for return to play decisions.

It is of particular note that ImPACT 3.0 was sensitive not only in the acute follow-up phase, but was also successful in revealing signs of persistent neurocognitive impairment. This was suggested by XY's lower than expected performance at preseason baseline testing relative to his estimated premorbid intellectual abilities on the initial screening battery. The presence of enduring sequelae was further supported by apparent fluctuations in XY's performance on the ImPACT 3.0 Visual Motor and Verbal Memory composites. Whereas there is ample prior literature revealing ImPACT's sensitivity to acute concussive effects (for example, Iverson et al., 2003; Lovell & Collins, 2002; Maroon et al., 2002), this appears to be the first formal attempt to document signs of persistent (chronic) deficits using ImPACT 3.0 in an individual case at the pre and post season phases. It is of note that with the identification of both the acute and chronic sequelae of concussion, the US normative data used on ImPACT 3.0 have been applicable for XY and have provided sensitive clinical indications of persistent deficits following multiple concussions. As indicated earlier, this is to be expected in an individual of relatively high level of functioning from a relatively advantaged educational background.

In the second aspect of the study, subtle indications of persistent neurocognitive deficit following multiple concussions on the initial neurocognitive screening tests were compared against the findings of a more in-depth neuropsychological test battery. The extended neuropsychological test battery also demonstrated sensitivity with regard to indications of persistent neurocognitive sequelae following multiple concussions, thereby confirming the findings of the initial neurocognitive screening battery. Adding validity to these findings is the fact that the deficit measurement mode of neuropsychological assessment of Lezak et al. (2004), as was employed in this study, is an internationally approved method used extensively in clinical practice as a means of identification of the effects of MTBI in the individual case.

In respect of specific items in the battery, the WAIS-III performance subtests, the complex hand/motor tasks, the unstructured verbal fluency test, and the WAIS-III Digit Symbol Incidental Recall test were most sensitive to MTBI indications in XY. The WMS-III Verbal and Visual Memory Indices were not as sensitive as ImPACT 3.0 Verbal and Visual Memory Composite, with the exception of the working memory component of the WMS-III. In comparison with the other measures used in this study, the Rey Complex Figure was the only test not to have indicated any cognitive deficits. Consequently, the indications from this case study are that in compiling an in-depth battery for the purposes of MTBI follow-up, the Rey Complex Figure test should be omitted.

In sum, the initial neurocognitive screening measures and the in-depth neuropsychological test battery (with the exception of the Rey Complex Figure test) have been shown to be sensitive to subtle persistent deleterious deficits following multiple concussions, particularly in the areas of information processing, visual memory, verbal working memory, verbal fluency and motor slowing. This was evident at both the pre- and postseason intervals. In contrast to this, it is of note that the ImPACT 3.0 Symptom Checklist only appeared sensitive at preseason testing. At postseason XY's symptom report was much reduced compared with baseline, and close to the normative indication on US data. In XY's case, this may be the result of underreporting purposefully to ensure quick return to play. Alternatively, it is possible that he was not fully aware of symptoms that might have emerged with further probing. In any event, the lack of symptom reports for XY at this junction support the observation that, used in isolation, pure reporting of symptoms might provide a false impression of recovery, which may have potentially severe management implications. This concurs with warnings in this regard in the sports concussion literature (Guskiewicz et al., 2004; Lovell & Collins, 2002).

4.3.3. Management implications

Prague Conference guidelines (McCrory et al., 2005) pertaining to multiple concussions suggest that instances involving a history of multiple concussions would be classified as a 'complex' concussion, and thereby necessitate neuropsychological testing. In accordance with sound neuropsychological practice the administration of more than one test is required for diagnostic clarity (Lezak et al., 2004; Mitrushina et al., 1999). The subtle indications of neurocognitive impairment found on the initial neurocognitive screening battery, and confirmed with the more expanded neuropsychological assessment suggest that lower than expected baseline scores on ImPACT 3.0, relative to estimated premorbid functioning, should warrant further neuropsychological investigation.

Athletes with a history of multiple concussions are likely to report enduring postconcussive symptoms (Iverson et al., 2003). Moreover these athletes are at significant risk of further concussive injuries (Cantu, 2001), which are likely to increase in severity (Iverson et al., 2003). In light of XY's concussive history, and the compelling evidence suggesting persistent cumulative neuropsychological deficits, it is possible that XY would be at a risk of increasingly severe injuries, and more apparent neurocognitive sequelae and neurobehavioural symptoms should he return to contact sports. Should XY continue to experience concussive insults, it is postulated that the potency of his brain reserve may further diminish, and give rise to more apparent and more significant neurocognitive impairment. As such, strong recommendations would be made regarding XY's abstention from contact sports, and therefore the avoidance of the possibility of further concussive injuries.

4.4. Evaluation of the study

4.4.1. Strengths of the study

This study appears to be the first of this type to apply an in-depth focus of a single case of sports-related concussion utilising ImPACT 3.0 in conjunction with a comprehensive neuropsychological test battery, especially devised to allow for an estimated IQ, and to be sensitive to MTBI. This allowed for a compelling corroboration of ImPACT 3.0's sensitivity to persistent cumulative neurocognitive deficits following multiple concussions by means of the more probing neuropsychological test battery.

4.4.2. Limitations of the study

A limitation pertaining to this study involves the fact that there was no neuropsychological testing prior to XY's participation in rugby, resulting in a lack of certainty regarding the origin of the indications of XY's neurocognitive deficits. The lack of previous cognitive testing relating to general intellectual functioning, which might verify estimates of premorbid functioning prior to his concussive injuries, meant that an estimate had to be made based on demographic information and the general intellectual functioning test battery conducted for the purpose of this study. It cannot, therefore, be ruled out that the neurocognitive deficits identified may be the result of prior undiagnosed neurocognitive vulnerabilities rather than as a result of multiple concussions. However, the assumptions of deficit measurement (Lezak et al., 2004), upon which this research analysis was based, are used regularly in clinical practice to provide aetiological and diagnostic implications in the absence of premorbid test results (for example, in the medico-legal post-MTBI assessment arena).

A further limitation in respect of this case study was that it was conducted on an individual with an estimated high level of intellectual functioning and relatively advantaged educational background. He was thus considered to have relatively high BRC. Thus, it is possible that the findings of this study may not be applicable to other individuals with a history of multiple concussions who do not have similar backgrounds, as these factors might give rise to differential effects on ImPACT 3.0. For example, individuals with greater BRC than XY (for instance, more superior levels of intellectual functioning and/or more advanced education) may not exhibit neurocognitive deficits on ImPACT 3.0. Similarly, individuals with lower BRC might score significantly lower than the US norms, suggesting more impairment than is actually present.

4.4.3. Recommendations for further research

On the basis of the present study, a number of recommendations for further research can be identified, as follows:

4.4.3.1. The need for further case studies

Although there is compelling evidence of signs of residual effects following multiple concussions, on both the initial neurocognitive screening measures and the supplementary in-depth battery, further case studies are needed, on similar level individuals, for replication purposes, as well as those of more- and less-advantaged intellectual capacity.

4.4.3.2. The need for longitudinal studies of cumulative neuropsychological effects of multiple concussions

Although prospective research is difficult to implement, it is recommended that longitudinal case studies be implemented prior to involvement with rugby and the concomitant likelihood of sustaining a concussion. Regular neuropsychological assessments should be conducted at 3 to 5 year intervals, alongside case-based controls, to determine the onset and presence of persistent neurocognitive sequelae following multiple MTBI in association with participation in a game such as rugby.

4.4.3.3. Further analysis of postconcussive symptoms

With regard to the ImPACT 3.0 21-item symptom questionnaire, XY's self-report of symptoms experienced was noted as consistently above the norm. Despite the suspicion regarding residual deficits following the multiple concussions, XY's postseason symptom level dropped to a level only slightly higher than the US normative range, suggesting a symptomatic recovery from the concussion. This was confirmed on the brief clinical interview, when XY reported no physical, cognitive or emotional difficulties. However, given the clear indication of areas of cognitive dysfunction on XY's in-depth neuropsychological assessment, it seems unlikely that this was entirely out of XY's awareness. Thus, this study may have been usefully augmented through the conducting of a more probing clinical interview and an expanded symptom checklist in order to bring such possible problems to the fore.

4.4.3.4. Adjustments to the in-depth neuropsychological test battery

In this study, the untimed copy task of the Rey Complex Figure Test was not shown to be sensitive to executive functioning deficits in XY. It is recommended that further case study research conducted in this area might replace the Rey Complex Figure copy task with the timed Stroop Test in the neuropsychological test battery. The Stroop Test (as cited in Lezak et al., 2004) may be administered in a number of formats, most of which are regarded as sensitive to the effects of MTBI, in particular the domain of executive functioning (Lezak et al., 2004). However, this addition would merely serve to augment the battery used for the present study. The battery as it stood proved to be sufficiently wide-ranging to substantiate persistent deleterious neurocognitive signs isolated on the initial ImPACT 3.0 screening test that were commensurate with the expected consequences of multiple concussions sustained in rugby. In turn this provided the necessary confirmation to advise against XY's further participation in a contact sport.

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APPENDIX A

PRE-SEASON QUESTIONNAIRE

CONFIDENTIAL

First Names: ______________________ Surname: ______________________

Date of Birth: ______________________ Age: ______________________

Highest educational qualification: ______________________

Degree for which you are currently registered? ____________ Current Year of study: ____________

Contact telephone number during university term: ____________ E-mail address: ____________

A. BACKGROUND INFORMATION

Last school attended: ______________________

Height: __________ m Weight: __________ kg

Right handed: ☐ Left-handed: ☐ (please tick)

Country of birth: ______________________ First Language: ______________________

Second Language: ______________ Years speaking second language: ______________

Please tick if any of the following are relevant to you:

- ☐ You have received speech therapy
- ☐ You have attended special classes or remedial classes
- ☐ You have received occupational therapy
- ☐ You have repeated any grades at school (please specify)
- ☐ You have repeated any subjects at university (please specify)
- ☐ You have been diagnosed with ADD or Hyperactivity
- ☐ You have been diagnosed with a learning disability

What winter sport(s) do you play?

SPORT	POSITION	WHAT TEAM WERE YOU IN LAST YEAR?	HOW MANY YEARS HAVE YOU PLAYED AT THIS LEVEL?

How many times have you sustained a concussion (ie. Felt dazed, dizzy or confused, however briefly, or unconscious)? ______________________

If you have sustained a concussion, please complete the following:

CONCUSSION	YEAR	REASON FOR CONCUSSION	SYMPTOMS EXPERIENCED ***(please tick)***			
			LOSS OF CONSCIOUSNESS ***IF YES, STATE DURATION***	CONFUSION	MEMORY DIFFICULTIES FOR EVENTS IMMEDIATELY AFTER INJURY	MEMORY DIFFICULTIES FOR EVENTS IMMEDIATELY BEFORE INJURY
1						
2						
3						
4						
5						
6						
7						

Please indicate whether you have experienced the following:

	YES	NO
Treatment for headaches by physician		
Treatment for migraine headaches by physician		
Treatment for epilepsy/ seizures		
History of meningitis		
Dependency on alcohol		
Dependency on drugs		
Treatment for alcohol abuse		
Treatment for drug abuse		
Treatment for psychiatric condition (depression, anxiety etc.)		

B. CURRENT SYMPTOMS AND CONDITIONS

Hours of sleep last night ______________

Current medications ______________________________

Average weekly alcohol consumption ______________________________

Average daily alcohol consumption ______________________________

Tick the appropriate column which indicates the degree to which you are currently experiencing the following:

	Not experiencing		Somewhat		Severe
	1	2	3	4	5
Headache					
Nausea					
Vomiting					
Poor appetite					
Balance problems					
Dizziness					
Fatigue/ Tiredness					
Trouble falling asleep					
Sleeping more than usual					
Sleeping less than usual					
Drowsiness					
Sensitivity to light					
Sensitivity to noise					
Difficulty hearing					

Irritability					
Aggression					
Sadness					
Nervousness					
Feeling more emotional					
Numbness or tingling					
Feeling slowed down					
Feeling mentally foggy					
Difficulty concentrating					
Difficulty remembering					
Visual problems (blurring or double vision)					
Speech problems					