A CASE STUDY INVESTIGATION INTO THE UTILITY OF BASELINE DATA VERSUS NORMATIVE DATA USING A COMPUTER-BASED CONCUSSION MANAGEMENT PROGRAMME.

A thesis submitted in partial fulfilment of the
requirements for the degree of

MASTERS OF ARTS

IN COUNSELLING PSYCHOLOGY

of

RHODES UNIVERSITY

by

JULIA MITCHELL

SUPERVISOR: PROFESSOR ANN EDWARDS

June 2005

ABSTRACT

Neuropsychological testing is recognised as one of the cornerstones of concussion evaluation, contributing significantly to both an understanding of the injury as well as management of the recovery process. Despite the high incidence of concussion at school level, traditional paper-and-pencil neuropsychological testing has generally been absent from school concussion management programmes, largely due to time and cost constraints. Now, the recent development of computerised neuropsychological testing is providing the opportunity for including neurocognitive assessment in this process. The Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) is a valid and reliable instrument of this type and normed on 13 - 18 year old North American high school athletes, as well as adult groups. The current recommendation is that athletes are baselined preseason in order to provide an individualised comparative level against which to monitor recovery and provide return-to-play recommendations. This in itself is quite a cumbersome process, thus the present study set out to ascertain whether baseline testing of all athletes is necessary, or whether the use of US or SA normative data alone would provide an appropriate standard against which to interpret the postinjury scores. From a leading South African rugby playing school, the 1st and 2nd rugby teams, (16 - 18 years) were baselined using ImPACT. Three athletes, who were subsequently referred with concussion during the rugby season, were followed up with serial testing on ImPACT. An analysis of the follow up scores was conducted to chart the athletes' recovery process, in relation to the athletes own baseline scores (using US and SA reliable change indices) and age appropriate US and SA normative ranges. The relative utility of individual baselines scores versus these normative ranges was then critically evaluated. It was concluded that a combination of both baseline and normative data provided optimal management of the athlete, with the methods complementing each other in the interpretation of post-injury results. Overall, the SA normative ranges seemed to provide slightly better management guidelines than the US normative ranges when used with this sample of South African high school athletes.

TABLE OF CONTENTS

Chapter 1: LITERATURE REVIEW

1.1 Defining and recognising concussion 1

1.2 Grading and determining severity 3

1.3 Pathophysiological consequences and sequelae 6

1.3.1 Second Impact Syndrome (SIS) 7

1.3.2 Threshold Theory 9

1.4 Management 10

1.4.1 On-field/sideline evaluation 12

1.4.2 Off-field management 13

1.4.2.1. Neuropsychological testing 13

1.4.2.2. Traditional versus Computerised Neuropsychological tests 14

1.5 Return to Play protocol 19

1.6 The young athlete 20

1.6.1 Differences between child and adult concussion 20

1.6.1.1 Pathophysiological 20

1.6.1.2 Neuropsychological 21

1.6.1.3 Management 21

Chapter 2: METHODOLOGY 23

2.1 Participants 23

2.2 Assessment Instruments 25

2.2.1 Pre-season questionnaire 25

2.2.2. ImPACT 25

2.3 Procedures 30

2.4 Data analysis 31

Chapter 3: CASE STUDIES 32

3.1 Case Study 1 33

3.2 Second reported concussion for Case Study 1 42

3.3 Case Study 2 49

3.4 Case Study 3 60

Chapter 4: DISCUSSION 67

4.1 The diversity of concussive injury presentations 69

4.2 The utility of the neuropsychological test in the follow-up process 70

4.3 Methods of interpretation: baseline scores combined with Reliable Change Indices versus Normative ranges 72

4.4 The impact of co-morbidity on test results 77

4.5 Management recommendations for athletes 79

4.6 Evaluation of the study 79

4.6.1 Limitations of the study 79

4.6.2 Strengths of the study 80

4.7 Conclusion 80

REFERENCES 82

List of Figures

Figure 1.1 Case 1: Scores for the Verbal Memory composite at baseline and at the three post-concussion tests. 37

Figure 1.2 Case 1: Scores for the Visual Memory composite at baseline and the three post-concussion tests 37

Figure 1.3 Case 1: Scores for the Processing Speed composite at baseline and at the three post-concussion tests 37

Figure 1.4 Case 1: Scores for the Reaction Time composite at baseline and at the three post-concussion tests 37

Figure 1.5 Case 1: Scores for the Symptom Scale at baseline and at the three post-concussion tests 38

Figure 1.6 Case 1: second concussion: Scores for the Verbal Memory composite at baseline and at the two post-concussion tests 45

Figure 1.7 Case 1: second concussion: Scores for the Visual Memory composite at baseline and at the two post- concussion tests 45

Figure 1.8 Case 1: second concussion: Scores for the Processing Speed composite at baseline and at the two post-concussion tests 45

Figure 1.9 Case 1: second concussion: Scores for the Reaction Time composite at baseline and at the two post-concussion tests 45

Figure 1.10 Case 1: second concussion: Scores for the Symptom Scale score at baseline and at the two post-concussion tests 46

Figure 2.1 Case 2: Scores for the Verbal Memory composite at baseline and at the five post-concussion tests 53

Figure 2.2 Case 2: Scores for the Visual Memory composite at baseline and at the five post-concussion tests 53

Figure 2.3 Case 2: Scores for the Processing Speed composite at baseline and at the five post-concussion tests 53

Figure 2.4 Case 2: Scores for the Reaction Time composite at baseline and at the five post-concussion tests 53

Figure 2.5 Case 2: Scores for the Symptom Scale score at baseline and at the five post-concussion tests 54

Figure 3.1 Case 3: Scores for the Verbal Memory composite at baseline and at the three post-concussion tests 63

Figure 3.2 Case 3: Scores for the Visual Memory composite at baseline and at the three post-concussion tests 63

Figure 3.3 Case 3: Scores for the Processing Speed composite at baseline and at the three post-concussion tests 63

Figure 3.4 Case 3: Scores for the Reaction Time composite at baseline and at the three post-concussion tests 63

Figure 3.5 Case 3: Scores for the Symptom Scale score at baseline and at the two post-concussion tests 64

List of Tables

Table 1. American Academy of Neurology Concussion Grading Scale 4

Table 2. Identifying Data for participants sustaining concussive injuries 25

Table 3. A comparison of United States and South African normative data for ImPACT for high school boys showing classification categories of performance based on percentile rankings. 28

Table 4. Classifications and raw scores derived from US and SA samples of high school athletes for the Symptom Scale scores. 28

Table 5. The US and SA Reliable Change Indices (RCI's) for ImPACT for the 80% confidence interval. 29

Table 6. Case 1: first concussion: Summary of the ImPACT test results for the baseline test and three post-concussion tests as well as the US and SA Normative Data for high school boys ages 16 - 18 years in the average range. 35

Table 7. Case 1: first concussion : Self-reported post-concussion symptoms from the ImPACT Symptom Scale at baseline and the three post-concussion tests. 36

Table 8. Case 1: second concussion: Summary of the ImPACT test results for the baseline test and two post-concussion tests, as well as the US and SA Normative Data for high school boys ages 16 - 18 years in the average range 44

Table 9. Case 1: Self-reported post-concussion symptoms from the ImPACT Symptom Scale at baseline and the two post-concussion tests 44

Table 10. Case 2: Summary of the ImPACT test results for the baseline test and the five post-concussion tests as well as the US and SA Normative Data for high school boys ages 16 - 18 years in the average range 51

Table 11. Case 2: Self-reported postconcussion symptoms from the ImPACT Symptom Scale at baseline and at the five post-concussion tests 52

Table 12. Case 3: Summary of the ImPACT test results for the baseline test and three post-concussions tests, as well as the US and SA Normative Data for high school boys ages 16 - 18 years in the average range 62

Table 13. Case 3: Self-reported postconcussion symptoms from the ImPACT Symptom Scale at baseline and the three post-concussion tests 62

APPENDICES

Appendix A: Pre-Season Questionnaire 87

Appendix B: Headmaster Consent Form 88

Appendix C1: Covering letter for parents re: concussion in school sport 89

Appendix C2: Brief to parents regarding concerns about pupil participation in research 90

Appendix D: General information for pupils and pupil consent form 91

ACKNOWLEDGEMENTS

I would like to thank

- Professor Ann Edwards, for her helpful guidance and supervision

- My family, for their support and encouragement

Chapter 1: LITERATURE REVIEW

1.1 Defining and recognising concussion

The phenomenon of concussion, a term used interchangeably with mild traumatic brain injury (MTBI), has been broadly described as “a trauma-induced alteration in mental status that may or may not be accompanied by loss of consciousness” (Collins, Lovell and McKeag, 1999). Another definition which gives a detailed working description of concussion was suggested by the American Orthopaedic Society for Sports Medicine (AOSSM) Concussion Workshop Group (Wojtys et al., 1999), namely “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 acute signs or symptoms: a brief loss of consciousness (LOC), light-headedness, vertigo, cognitive and memory dysfunction, tinnitus, blurred vision, difficulties in concentration, 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” (p.676). The AOSSM definition reveals the wide range of symptomatology that has been associated with concussion. This variability of concussive symptoms has been part of the difficulty in arriving at a universally agreed upon definition and by extension, difficulty in reaching consensus on concussion management. Some of the symptoms from the AOSSM definition have been validated including amnesia, LOC, headache, dizziness, blurred vision, attention deficit and nausea, with headache not only due concussion alone (McCrory & Johnston, 2002). Validation of the remaining symptoms as a direct consequence of concussion, and not due to factors such as malingering or social environment, is less clear cut (LeClerc, Lassonde, Delaney, Lacroix & Johnston, 2001; McCrory & Johnston, 2002).

Defining and classifying traumatic brain injury (TBI) in general, alternatively referred to as 'head injury' is characteristically difficult because presentations are “heterogenous, characterised by a multitude of neuropsychological profiles and diverse patterns of cognitive, emotional, behavioural and sensorimotor symptoms” (Hanlon, Demery, Martinovich & Kelly, 1999, p.873). TBI has been classified on a continuum from severe to mild (Satz, 2001).

Within the clinical, as well as athletic context, concussion falls within the mild end of the spectrum (Guskiewcz et al., 2004). While the criteria for severe and moderate traumatic brain injury are relatively well defined and validated on the Glasgow Coma Scale (GCS), the criteria for MTBI (i.e. concussion) are not clear due in part to its particularly variable presentation (Comerford, Geffen, May, Medland, & Geffen, 2002). Various measurable and observable characteristics of acute neurological status have been suggested as clinical and research criteria for determining a MTBI, namely: a score of 13 – 15 on the GCS; no LOC or a period of LOC less than 20 – 30 minutes; the absence of focal neurological signs (suggesting the presence of subdural hematoma); a period of post traumatic amnesia (altered state) less than 1 hour - although some grading scales would put this at less than 24 hours; head trauma due to contact forces or acceleration/deceleration forces without direct contact; as well as negative neuroimaging studies (Comerford et al., 2002; Hanlon et al., 1999; Satz, 2001).

Different combinations of the above sets of criteria form part of a number of different classification scales for differentiating MTBI from moderate and severe injuries, none of which have been fully validated (LeClerc et al., 2001). The scales therefore represent a view from different experts rather than a consensus of scientific evidence (LeClerc et al., 2001). While these classifications may be useful in placing MTBI (as distinct from moderate and severe TBI) within the context of TBI in general, they do not offer much for the sports context where the difficulties lie particularly in recognising the most subtle indicators of the so-called “ding” or mild concussive brain injury (LeClerc et al., 2001). It has been recognised that “the most progressive advances regarding the diagnosis and grading of severity of MTBI have been made in the sports arena" (Hanlon et al., 1999, p.874). Recent developments achieved in the diagnosis and management of such concussions are related to the fact that sports concussions are often observed and immediately assessed by health care professionals, whereas civilian concussions are rarely observed (Hanlon et al., 1999).

In recent years international concern over the potential for negative outcomes arising from concussive injuries in sport have resulted in two international conferences being convened: the First International Conference on Concussion in Sport held in Vienna in 2001 (Aubrey et al., 2001) and the Second International Conference on Concussion in Sport in Prague, 2004

(McCrory et al., 2005). These conferences have aimed to provide consensus statements for the improvement of safety and health of athletes who suffer concussive injuries in a spectrum of sports including for example, ice hockey and football (soccer) (McCrory et al., 2005). For the purpose of this discussion, the consensus statements arising out of these two conferences, will be referred to as the Vienna Statement, 2001 (Aubrey et al., 2001) and the Prague Statement, 2005 (McCrory et al., 2005).

The following definition of concussion appears in the Vienna guidelines:

> Concussion is defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces. Several common features that incorporate clinical, pathological and biomechanical injury constructs that may be used in defining the nature of a concussive head injury include: 1) Concussion may be caused 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 of neurological function that resolves spontaneously. 3) Concussion may result in neuropathological changes but the acute clinical symptoms largely reflect a functional disturbance rather than a structural injury. 4) Concussion results in a graded set of clinical syndromes that may or may not involve loss of consciousness. 5) Resolution of the clinical and cognitive symptoms typically follows a sequential course. Concussion is typically associated with grossly normal structural neuroimaging studies. (Aubry et al., 2001, p. 6)

The same definition was retained in the Prague Statement, but with an important proviso, namely that "in some cases post-concussive symptoms may be prolonged or persistent" (McCrory et al., 2005, p.196).

1.2 Grading and determining severity

In 1966, the subcommittee on Classification of Sports Injury (from the Congress of Neurological Surgeons) devised a system to grade the severity of concussion injuries along a continuum, i.e. grades 1, 2 and 3, (mild, moderate and severe, respectively) (LeClerc et al., 2001; Guskiewicz et al., 2004). This grading system served as a basis for many subsequent concussion grading scales that were developed, such as those set by Cantu (1986), the Colorado Guidelines (1991) and the American Academy of Neurology (AAN) Guidelines (1997) (Maroon et al., 2000). For a typical example of one of these grading scales see Table 1 below (adapted from Maroon et al., 2000, p.661).

Table 1. American Academy of Neurology Concussion Grading Scale

Grade	*American Academy of Neurology (AAN)*
Grade 1 (mild)	No LOC*; transient confusion; concussion symptoms or mental status abnormality resolved in < 15 min
Grade 2 (moderate)	No LOC; transient confusion; concussion symptoms or mental status abnormality last > 15 min
Grade 3 (severe)	Any LOC, either brief or prolonged

*LOC: loss of consciousness

Such grading scales aimed to provide guidelines to assist coaches, athletic personnel, physicians and others with the difficult decisions of diagnosing a concussive injury, measuring concussive severity and predicting prognosis and outcome (McCory & Johnston, 2002). Although these guidelines characteristically were attempts at systematically developed, evidence-based statements to facilitate practitioner and patient with a standard of care, none of the over 18 different concussion grading scales are solidly evidence based, representing instead a combination of clinical impression, anecdotal experiences and medical consensus (Lovell, Collins, Iverson, Johnston & Bradley, 2004; Peloso et al., 2004; Maroon, Field, Lovell, Collins & Bost, 2002; Terrell, 2004). These grading systems are designed around the presence and duration of particular concussion signs and symptoms, most commonly, LOC, orientation and posttraumatic amnesia (PTA) (McCory and Johnston, 2002). Although these guidelines show some similarity, there is sufficient disparity between them such that an athlete's concussion could be graded '1' using one scale and '2', using another (Hinton-Bayre & Geffen, 2002). Recent research has shown that certain of these traditional severity indicators, such as LOC, are in fact poor predictors of concussion severity (Lovell, Iverson, Collins, McKeag & Maroon, 1999; Field, Collins, Lovell & Maroon, 2003; Maroon et al., 2000). In a comparative study using three well known grading scales, i.e. AAN, Cantu and Colorado Medical Society, cognitive impairments were still evident at day 10 for some grade 1 and grade 2 concussions, with no persisting impairment present at day 10 for any of the grade 3 rated concussions from any of the scales (Hinton-Bayre & Geffen, 2002). Other studies have found no significant difference in severity of cognitive impairment amongst LOC and no LOC groups (Lovell et al., 1999). There is ongoing research aiming to establish an empirical basis for grading concussions such as Erlanger, Kaushik et al.'s (2003) study on a symptom-based assessment of the severity of a concussion.

Accordingly, none of the existing grading scales were endorsed in the Vienna Statement and it was recommended that combined measures of recovery (such as sideline evaluation, and neuropsychological testing) be used to assess injury severity (Aubrey et al., 2001). More recently, the National Athletic Trainers Association (NATA) Position Statement on concussion management in sport (2004) notes three current approaches to grading: 1) Grading at the time of injury following one of the current guidelines (such as the AAN) on the basis of signs and symptoms present in the first 15 minutes of injury (while recognising the limitations of taking a generalised approach). 2) A retrospective approach - grading of the injury after all the concussion signs and symptoms have resolved (eg Cantu Evidence-Based Grading Scale). 3) A third approach does not use a grading scale at all but outlines a multitiered approach as suggested by the Vienna Statement i.e. one which utilises a combination of assessment measures such as symptoms scales, neuropsychological tests and postural-stability tests, with a focus on individual recovery. Similarly, individualised management using various measures of recovery was also endorsed in the Prague Statement (2005) along with a retrospective approach to grading (McCrory et al., 2005). In sum, it would appear that the difficulties inherent in categorising and grading severity of MTBI have created a consensus of opinion to move away from the classification of MTBI via the use of grading scales.

In an apparent contradiction to this development, the Prague Statement (2005) has also included a new method of classifying concussion - as either 'simple' or 'complex'. Cited as a 'key development', brief definitions of these categories are given along with management recommendations. 'Simple' concussion is defined as a concussive injury that progressively resolves without complications over 7 - 10 days (with classification, it is assumed, taking place retrospectively, although this is not clear). Grouped under 'complex' concussions are those cases which are at greater risk for complications, namely where athletes suffer persistent symptoms, specific sequelae (such as concussive convulsions), LOC longer than one minute, prolonged cognitive impairment after injury, history of concussions or where repeated concussions occur with progressively less impact force (McCrory et al., 2005). Despite being depicted as a 'key development', this new classification system does not appear to offer any further clarity or suggestions regarding the perennial problems which contributed to the loss of confidence in a categorising approach i.e. underreporting by athletes, vague concussion histories, subtle and/or delayed cognitive impairments and varied symptomology.

1.3 Pathophysiological consequences and sequelae

The biomechanics of the concussive injury, outlined by Poirier, (2003) are summarised below: when a person is in a resting state and their head is forcibly struck by another object, maximal brain injury occurs beneath the point of cranial impact, known as a coup injury. In the situation when a person is moving and their head then collides with a non moving object such as the ground or pole, maximum injury to the brain is produced at the opposite site of the cranial impact, known as a contra-coup injury. A phenomenon called “impulsive loading” occurs when the person's head is set into motion as a result of forceful impact to another part of their body.

The term “concussion” is derived from this movement of the brain within the skull, meaning “to shake violently” (Philips, 2003). The brain is suspended within the skull in cerebrospinal fluid, with several dural attachments to bony ridges that make up the inner contours of the skull (Guskiewicz et al., 2004). The force of the impact transmits a rapid acceleration-deceleration to the brain causing it to move in a linear direction either front to back or side to side or, in the more severe instances, in a rotational movement as well (Guskiewicz et al., 2004). The type of injury that results from the biomechanical forces described above is known as a diffuse brain injury, because it typically results in widespread disruption of neurological function rather than visible or structural damage. Concussion is thus classified as a mild diffuse injury due to the typically short lived nature of the incurred symptoms such as brief LOC, feelings of nausea, disturbances of vision and equilibrium etc (Guskiewicz et al, 2004). This statement reflects the typically transient nature of the majority of concussive injuries which resolve without any apparent negative repercussions (Lovell & Collins, 1998). A number of recent studies involving traditional neuropsychological measures have shown that most mild concussive injuries will resolve by 5 - 10 days (Macciochi, Jeffrey, Alves, Rimel & Jane, 1996; Echemendia, Putukian, Scott Mackin, Julian & Shoss, 2001; Field et al., 2003). However, other studies of so-called mild concussions, have shown impairment persisting beyond this period (Field et al., 2003; Hinton-Bayre & Geffen, 2002). An “as-yet-unknown number of these athletes may experience chronic sequelae which for some may be permanent and disabling” (Lovell & Collins, 1998, p.6). Research has shown that undiagnosed or unresolved concussion could put athletes at risk for cumulative or catastrophic injuries such as Second Impact Syndrome (Almquist, 2001).

1.3.1 Second Impact Syndrome (SIS). Although the outcome of sports concussion is often not of a critical nature, death due to subdural or epidural hematoma or SIS is a real possibility (Fisher & Vaca, 2004). The National Center for Catastrophic Sports Injury Research identified thirty-five probable cases of SIS between 1980 and 1993 (Fisher & Vaca, 2004). Although SIS was first described in 1975, some disagreement exists regarding the definition and actual existence of the entity, with discussion and investigation ongoing (Fisher & Vaca, 2004). However, certain common clinical features have been found in most of the SIS cases namely: a pre-existing head injury, persistent concussive-type symptoms (often under-recognised) and a "second impact" to the head or body of the athlete (Fisher & Vaca, 2004).

The concept of injury-induced vulnerability is used to explain the state of brain cells that are not irreversibly destroyed by the injury, but remain in an extremely vulnerable state (Wojtys et al., 1999). Studies of severe head injuries in humans and animals, indicate an extreme vulnerability to the consequences of even minor changes in cerebral blood flow and/or increases in intracranial pressure and apnea. (Wojtys et al., 1999). Time frames of vulnerability are not yet clearly established, but could last from a few minutes to several weeks (Wojtys et al., 1999). Experimental studies indicate that a disturbance in metabolic autoregulation creates this vulnerable state, characterised by an increased demand for glucose and an inexplicable reduction in cerebral blood flow (Wojtys et al., 1999). The result is an inability of the neurovascular system to respond to increasing demands for energy to re-establish its normal chemical and ionic environments, a potentially dangerous outcome as the altered environment can kill brain cells (Wojtys et al., 1999). In the case of SIS:

> ...the athlete's brain is believed to have preexisting cerebral edema and the second impact precipitates a loss in the ability of the brain to autoregulate intracranial and cerebral perfusion pressure. What follows has been described as a subsequent massive cerebral hyperemia and cerebral edema followed by fatal herniation (Fisher & Vaca, 2002, p. 264).

Profound brain damage or death can occur within a few minutes, leaving little time for emergency interventions (Fisher & Vaca, 2004).

Other immediate complications arising from concussion include intracranial space-occupying lesions and impact convulsions (Kohler, 2004). While signs of raised intracranial pressure needs to be treated immediately, impact convulsions have a good outcome and do not have require anti-epileptic medication or preclusion from sport (Kohler, 2004). Late complications of concussion include symptoms which have been found to persist from 6 weeks to three months (said to affect 10-15% of concussed persons) as well as the growing concern that repeated concussions may result in chronic brain injury (Kohler, 2004). Evidence for chronic sequelae from repeated mild concussions is provided by recent studies which suggest that athletes with multiple concussions are more likely to report ongoing postconcussion symptoms (Iverson, Gaetz, Lovell & Collins, 2002; Shuttleworth-Edwards, Border, Reid & Radloff, 2004), perform slightly worse on preseason cognitive testing (Iverson, Gaetz, et al., 2003; Shuttleworth-Edwards et al., 2004; Collins et al., 1999) and appear to be more vulnerable to sustaining injuries of greater severity in the future and suffer from more adverse consequences in the first two days post-injury (Iverson, Gaetz et al., 2003). In addition, further research indicates the possibility of structural damage falling below the current threshold of detection (McAllister & Arciniegas, 2002; Mathias, Beall and Bigler, 2004), all of which casts doubts on the so-called *transient* nature of the injury. It would seem that findings such as these prompted the amendment to the definition of the Vienna Statement (2001) (McCrory et al., 2005) (see definition section) regarding the potential for persistent symptomology. Potential risk factors for sequelae and poor recovery after concussion include, a prior history of brain injury, premorbid cognitive, attention and/ or behavioural impairments (McCrory, P.R., Collie, A., Anderson, V., & Davis, G., 2004). The growing awareness of the potentially negative consequences of a concussive injury is reflected in the recommendations of the NATA Position Statement, (2004), where particular mention is made of the so-called "ding" injury, a stunned confusional state only a few minutes in duration: it was suggested that the term “ding” is no longer used as it diminishes the potential seriousness of the injury, which, at the very least, is a mild concussion (Guskiewicz et al., 2004).

1.3.2 Threshold or Brain Reserve CapacityTheory (BRC). The concept of a threshold factor has been used in the medical field to explain individual protection from or vulnerability to clinical symptoms caused by ageing, dementia and Parkinsons's Disease (Satz, 1993). Using the concept of *brain reserve capacity* (BRC), Satz (1993) provides a preliminary theoretical formulation of the threshold theory to explain individual threshold differences in the onset of clinical symptoms or impaired neuropsychological test performance after brain injury. Satz (1993) suggests that BRC be regarded as a hypothetical construct that is related to adaptive behaviour, general intelligence and educational level. Satz (1993) proposes that greater BRC can act as a protective factor against functional impairment caused, for example by a brain lesion. Conversely, a similar lesion in the case of a person with less BRC, is more likely to result in neuropsychological impairment. That is, where the margin of brain reserve is less, vulnerability and the risk of impairment is greater. In addition it is hypothesized that in cases of multiple lesions or with a combination of vulnerability factors, the aggregate effect may lower the reserve capacity and threshold level, with earlier onset more likely with those individuals with less BRC (Satz, 1993).

In their study of athletes with a history of multiple concussions, Collins et al. (1999) observed long-term cognitive deficits in the domains of executive functioning and processing speed amongst athletes with 2 or more episodes of concussion. Their studies also illustrated the summative effect of multiple concussions with a learning disorder (LD) where athletes presenting with both multiple concussions and LD performed in the impaired range on tests of executive functioning and processing speed, i.e. more poorly than those with a history of prior concussions alone. Authors Collins et al. (1999) hypothesize that a lower reserve of BRC may have been present amongst athletes with LD resulting in a lower threshold for showing neuropsychological dysfunction. In the case of poorer test performance amongst athletes with 2 or more prior concussions in comparison to athletes with 1 or less, a similar conclusion may be drawn. This theory, used to explain the variable responses between individuals to injury and disease, highlights the inherent differences amongst individuals in their physiological reaction to injury and capacity for recovery. In addition this theory serves to explain mild head injury in conjunction with vulnerability factors such as a learning disorder or other neuropsychiatric disorders, as well as the potentially detrimental effect of multiple mild concussions on cognitive functioning.

1.4 Management

The classification scales for grading concussions into grades 1, 2 and 3 (mild, moderate and severe categories, append management recommendations at each level of severity (Maroon et al., 2002). With the multitude of grading scales reflecting a lack of consensus and evidence based data, it is not surprising that management recommendations vary widely and at present there are no universally accepted recommendations for concussion management (Aubrey et al., 2001; Peloso et al., 2004). Despite their limitations, management guidelines have provided certain benchmarks for coaches and medical personnel which have generally led to a greater degree of caution in managing the concussive injury (Lovell et al., 2004). NATA's position statement, (2004), however, reports that guidelines are often not followed consistently: on average 30% of all high school and collegiate players sustaining concussion return to play on the same day of injury, while the remaining 70% average 4 days rest before returning to full participation, which is considerably less than the general recommendation of a 7 days symptom free recovery period for grade 1 or grade 2 concussions suggested by many guidelines (Guskiewicz et al., 2004).

Management guidelines based on grading classifications may fail to take the individual variability of concussion injuries and varying rates of recovery into account: Differences in the type of biomechanical impact, anatomical location and severity of the injury can result in varied symptoms such as memory disturbances, learning problems, slow reaction times, physiologic symptoms with no cognitive decline or conversely, no symptoms and frank cognitive declines (Echemendia et al., 2001). While some athletes may take days to recover, others may take weeks (Echemendia et al., 2001; Kohler, 2004). Recent studies show significantly different neurocogntive recovery curves amongst various age groups (Field et al., 2003; McCrory et al., 2004). It is has also been suggested that response to and recovery from concussion may in part be affected by genetic factors, namely genetic phenotype (apolipo protein epsilon 4 (ApoE4) positive versus ApoE4 negative (Aubry et al., 2001; McCrory et al., 2005). Recognition of the various factors which may operate independently or together have resulted in some speculation regarding subtypes of concussion injuries, but further research is still necessary to clarify these ideas (Aubry et al., 2001; McCrory et al., 2005). In sum, the utilisation of generalised guidelines could result in certain athletes being returned to play too early and therefore increasing the risk for further neurological injury, while other athletes may be kept out longer than necessary (Maroon et al., 2000). Revised management guidelines based on the latest concussion statements are currently being devised, such as that by Kohler (2004), namely *Concussion in sport: practical management guidelines for medical practitioners.*

Concussion consensus statements are currently recommending an *individualised* approach to concussion management, centered on preseason baseline testing (Guskiewicz et al., 2004). Baseline cognitive testing using a combination of sideline tests (such as the Standardised Assessment of Concussion - SAC) and more extensive neuropsychological tests, where possible, has been recommended (Guskiewicz et al., 2004). Baseline scores for postural stability such as the Balance Error Scoring Sytem (BESS) as well as a self reported symptom score comprising those symptoms known to be affected by concussion, is also advised (Guskiewicz et al., 2004; McCrory et al., 2005). An athlete's own set of baseline scores provides a comparative measure against which postinjury scores can be assessed (Grindel, Lovell & Collins, 2001; Collie, Darby & Maruff, 2001). Baseline testing also controls for extraneous variables such as high or very low functioning, previous head injury, psychiatric problems, test anxiety, attention deficit disorder, learning disability and educational background (Grindel et al., 2001). When using normative data, in the absence of baseline scores, these variables can confound test results, and consequently affect interpretation of scores (Grindel et al., 2001).

From the variety of measures described above, it can be seen that not only is an individualised approach necessary, but a *multifaceted* assessment of the concussion injury and recovery process, is being increasingly recommended. The combination of measures allows for the inclusion of the subjective measure of a pre- and postconcussion symptom scale, as well the objective measures of neuropsychological testing and postural-stability, with the inclusion of neuroimaging possibly in the future (Aubrey et al., 2001; Guskiewcz et al., 2004; Susco, 2003). Concussion managment procedure includes assessment and evaluation at the time on injury, namely on-field/sideline evaluation as well as off-field follow-up assessments and management. A general outline of procedures and assessment tools follows below:

1.4.1 On-field/sideline evaluation

In the event of a concussive injury, the first stage in managing the injury is conducted by medical personnel and concerns the immediate safety of the athlete, including the assessment of whether any life threatening emergencies, neurological or orthopedic injuries exist and require on-field management (Susco, 2003). Subsequently, a brief cognitive test such as the Standardised Assessment of Concussion (SAC), the Balance Error Scoring System (BESS), and a rating on a postconcussion symptom scale may be administered and are described below (Aubrey et al., 2001; Susco, 2003): The brief sideline cognitive tests (such as the SAC) provides a tool for assessing the injured athlete's mental status immediately after the injury (Guskiewcz et al., 2004). These brief cognitive tests (often only taking 5 -10 minutes) are not meant to replace the more comprehensive neuropsychological test, but have been shown to be useful in classifying concussed from nonconcussed controls (Barr & McCrea, 2001). The standard approach of asking general orientation questions have largely been replaced by those questions involving recent memory, which has been shown to be more susceptible to change in the concussive type of injury (LeClerc et al., 2001; Kohler, 2004). Although the SAC has been shown to detect injury immediately after the injury and at 15 minutes post-injury, it is not able to discern the delayed onset of subtle deficits typically found only at 48 hours post-injury (Collins et al., 1999; McCrea, Kelly, Randolph, Cisler & Berger, 2002). The BESS has a good test-retest reliability and good concurrent validity and can be used as a clinical measure in identifying balance impairment which could be indicating the presence of a concussive injury (Guskiewicz, 2004). Postconcussion symptom scales generally consist of about twenty symptoms and signs associated with concussion and graded on a Likert-type scale, such as the Graded Symptom Checklist (GSC) devised by Guskiewicz et al. (2004). A thorough medical evaluation is also advisable (Aubry et al., 2001; Kohler, 2004; McCrory et al., 2005).

1.4.2 Off-field Management

Off-field management should include a medical assessment and an ongoing monitoring of postconcussive symptoms to be able to discern any deterioration of symptoms (Kohler, 2004). Any worsening of symptoms should be regarded as a medical emergency (Kohler, 2004). In certain cases where structural damage is suspected and complications such as prolonged disturbance of consciousness occurs, neuroimaging or CAT scans may be requested by the doctor (Aubrey et al., 2001). Neuropsychological testing is seen as a key component for off-field managment (Aubry et al., 2001; McCrory et al., 2005).

1.4.2.1 Neuropsychological testing. Neuropsychological testing (as distinct from the brief sideline cognitive test) has been found to be particularly useful to detect neurocognitive impairment and chart recovery (Barr & McCrea, 2001). Recent research showing the delayed onset and resolution of cognitive deficits, even after the athlete's physical symptoms appear fully resolved, highlights the important role that neuropsychological testing can play in concussion management (Field et al., 2003). Neuropsychological testing is also useful in overcoming the limitations of subjective questioning, where an athlete may underreport or be unaware of his or her concussive symptoms (Erlanger, Kaushik, et al., 2003; Susco, 2003). Recommendations from the recent Prague Statement (2005) state that neuropsychological testing is not required for simple concussion, and may be necessary only in cases of complex concussion. Research studies (such as those mentioned in the review above), however, suggest that the only way to discern the severity or resolution of the concussion is by neuropsychological testing. The neuropsychological testing procedure includes the preseason baseline test and subsequent followup testing in the event of a concussion. There are currently two methods of follow-up testing: the first is to follow up at prescribed intervals post-injury, while the second method is to begin testing once the athlete is asymptomatic (Guskiewicz, 2004). While practically it may seem unnecessary to begin testing while the athlete is symptomatic and being withheld from play, at the current stage of research serial testing can yield important data (Guskiewicz, 2004). Furthermore, serial testing may be a crucial factor in detecting postconcussive complications (Lovell, personal communication, 2005). Once the athlete's postinjury neuropsychological test scores have reached baseline (along with a medical clearance), the athlete may be allowed to return to play. Echemendia et al. (2001) have cautioned that a return to baseline levels may not be a sufficient indicator of "normal" functioning, but that the athlete may need to exceed baseline scores, particularly on measures with known practice effects.

“The value of the neuropsychological test score, rests on the instrument's ability to detect a positive result in a reliable and valid manner while yielding a negative test result for the individual without actual impairment” (Barr & McCrea, 2001, p.693). Collie, Maruff, McStephen & Darby (2003) point out that "the ability to detect subtle changes in an athlete's neuropsychological test performance such as those commonly observed after concussions is largely an issue of test reliability" (p.556) such that any change in measurement is indicative of change from the injury rather than normal fluctuation or measurement error. Reliability can be defined as the ability of a test to consistently measure a certain cognitive domain over a number of testing periods, without being affected by practice effects (ImPACT, 2005). Validity refers to the ability of the test to be sensitive to what it sets out to test, i.e. to be able to distinguish concussed athletes from non-concussed athletes (ImPACT, 2005). "The validation of neuropsychological tests is a gradual process, involving numerous studies over extended periods of time. One aspect of validity is to correlate computerized test scores with traditional test scores to better understand the presumed underlying constructs being measured by the computerized tests" (Iverson, Lovell & Collins, in press). As tests measuring abstract constructs such as cognition are more prone to error, it is particularly important that the psychometric properties are well designed and tested (Collie, Maruff, McStephen et al., 2003).

1.4.2.2 Traditional versus Computerised Neuropsychological Tests. The use of traditional pencil and paper neuropsychological testing in the sports arena has resulted in the development of a number of test batteries which include measures of cognitive abilities most susceptible to change after concussion, including attention and concentration, cognitive processing (speed and efficiency), learning and memory, working memory, executive functioning and verbal fluency (Guskiewicz et al., 2004). These protocols have been derived in part from a number of key research studies in over the past two decades, such as that conducted by Macciochi, Barth, Rimel and Jane, (1996): Their study, involving 2300 college athletes demonstrated impaired cognitive performance for sustained auditory attention, visuomotor speed, attention, concentration and memory problems, in the 183 athletes who sustained head mild injuries. Although traditional neuropsychological testing has led to an expansion of knowledge regarding the nature of sport-related concussive injuries, there have been certain limitations regarding the importing of these tests to the college and high school contexts, i.e. the relatively high cost of testing, lengthy time period required for testing, and a shortage of trained neuropsychologists to administer the test and interpret the results (Lovell & Collins, 2002). Collie et al. (2001) point out that the pencil and paper test batteries are also “not ideal for sporting settings as they are designed for the detection of gross deficits at a single assesssment, not for the identification of mild cognitive deficits on repeated assessment" (p. 297). Serial testing is often necessary in the off-field management of a concussion and many conventional tests do not have alternate forms (Collie et al., 2001). Traditional tests are also limiting in their restricted range of possible scores, floor and ceiling effects and poor test-retest reliability (Collie et al., 2001). Many of these problems are being overcome with the recent development of computerised neuropsychological testing which has the added advantages of increasingly accurate evaluation of response times as well as the facility for randomisation of stimuli to minimise practice effects (Lovell & Collins, 2002). The time and cost effectiveness of computerised testing has made neuropsychological testing an option for high schools for the first time (Lovell & Collins, 2002). Computerised testing, however, introduces its own unique set of challenges: the automated nature of the computerised measures does not allow for the collection of spontaneous verbal responses thus eliminating the ability to test verbal functioning and, being automated, is not as flexible as a one-on-one examination (Schatz & Browndyke, 2002; Schatz & Zilmer, 2003).

Whilst computerised testing can be done in large groups and is quick in comparison to the traditional pencil-and paper neuropsychological tests, it is still a challenge to integrate this procedure into a school schedule. Guidelines on implementing baselining on the various assessment instruments suggest that a time frame of three months be allowed to systematically plan and conduct baseline tests as well as obtain useful clinical background information on each athlete (Guskiewicz et al., 2004). As conducting regular assessments of large numbers of high school athletes can prove a logistical challenge, case studies presented by the ImPACT management team have shown promising indications that management of concussive injury using normative data is possible in the absence of baseline data (ImPACT, 2005).

Concern has been raised that computerised neuropsychological testing has not yet undergone sufficient reliability and validity testing, and that recommendation is premature at this stage (Schnirring, 2004). Physicians, Yorio and Grindel, believe that the current NATA recommendations (2004) could give the wrong impression - that computerised neuropsycholoical testing is an established "standard of care" - while it has not yet been validated to diagnosise concussion and is still in the research phase for gauging recovery (Schnirring, 2004). Guskiewicz, lead author of the NATA statement, defends the recommendation, however, saying that it is clearly stated that a thorough clincial evaluation should accompany use of neuropsychological testing and that many of the validation questions have been answered (Schnirring, 2004). It is generally agreed, however that when neuropsychological testing is used together with other clinical measures, it gives important objective data to assist and facilitate the detection and the management of concussion (Aubrey et al., 2001; Guskiewicz et al., 2004). Schatz and Zilmer (2003) have described the computerised assessment as a sophisticated screening test - while it does not provide a comprehensive evaluation of abilities, it does provide an objective evidence of neurocognitive strengths and weaknesses, as well as a pre-post comparison. If necessary, a more comprehensive paper and pencil neuropsychological test could be carried out for particular cases (Collie, et al., 2001).

As delineated in Guskiewicz et al. (2004), computerised neuropsychological tests currently available include: Immediate Postconcussion Assessment and Cognitive Test (ImPACT), the Concussion Resolution Index (Headminder), and Cogsport. An extensive review of the relative merits and demerits of each programme is beyond the scope of this thesis. However, it can be said that all three are relatively new developments, engaged in ongoing research to further validate their particular programmes in order to extend the general understanding of sports concussion and provide optimum safe management for the injured athlete. These examples of computerised neuropsychological preogrammes are outlined below.

Cogsport (Cogstate, 1999). A pack of playing cards is used as a visual stimulus to evaluaute changes in cognitive function. This computerised test battery includes measures of reaction time, sustained and divided attention, new learning and shortterm and working and incidental memory, adaptive problem solving spatial abilities and decision making (Schatz & Zilmer, 2003). The Cogsport report gives scores for psychomotor speed, decision making speed, problem solving speed and memory speed (Cogsport, 2005). Playing cards are used as test stimuli which are used to evaluate changes in cognitive function (Schatz & Browndyke, 2002). Performance variability or attention fluctuations, which is viewed as a key measure in concussion diagnosis by the Cogstate research team, are easily picked up by the more sensitive computer test in comparison to the single estimate of performance of traditional tests given over a very brief period (Makdissi et al., 2001). Validation studies have been conducted on Australian football players, which showed greater sensitivity to concussion injuries obtained from using a simple reaction time test from the Cogsport battery than from the Digit Symbol Substitution and Trail making tests (Makdissi et al., 2001). Some evidence of practice effects have been found over a brief test interval and there is some suggestion that the use of playing cards may affect outcomes (Collie, Maruff, Darby & McStephen, 2003). Namely, that the magnitude of practice effects would be reduced in some particpants who had had regular previous exposure to card games. Results are scored and analysed via e-mail (Schnirring, 2001). This presently limits its independent accessibility for research studies.

Concussion Resolution Index (Headminder Inc) (1999). The computerised test battery, modeled on traditional neuropsychological tests, consists of six subtests measuring reaction time, visual recognition and speed of information processing (Erlanger, Feldman et al., 2003). A symptom check list is included to chart resolution if symptoms as well as a short questionnaire to gather demographic information, concussion and medical history. Three factors are derived from the six subtests: 1) simple reaction time (i.e. speed of motor response to a visual cue), 2) complex reaction time (i.e. speed of decision making), and 3) visual scanning/ psychomotor speed. Focus on these particular cognitive functions was derived from research (Echemendia et al., 2001) which suggested that a reduction in speed of information processing may account for decreases in test performance across a range of cognitive function such as reaction time, psychomotor speed and memory (Erlanger et al., 2003). Research studies have shown that the programme is a valid and reliable measure of cognitive performance in a relatively heterogeneous group of athletes aged 13 -35 (Erlanger, Feldman et al., 2003). Strong concurrent validation was found with traditional neuropsychological tests measuring similar constructs, namely the Symbol Digit Modalities Test, Wechsler Adult intelligence Scale-Third Edition Digit Symbol and Symbol Search subtests, Grooved Pegboard and Trail Making Tests, while divergent validity was found with measures of attention (i.e. Digit Span) and reading speed. CRI has shown promising cross-cultural results when used by independent researchers (Headminder, 2003). It can be purchased, administered and interpreted by authorised, registered providers and used for decisions regarding concussion severity, return-to -play decisions and for research purposes, with results and reports avaliable immediately (Headminder, 2001).

ImPACT - Immediate Post-Concussion Assessment and Cognitive Testing (1998). ImPACT has been under development since 1994, with the first version released as a research battery in 1998 and implemented in certain universities, high school and professional teams. ImPACT 2.0 was released in 2002 with the addition of a Design Memory component. Most recently ImPACT 3.0 was published in 2004 to include percentile scores and the facility to incorporate reliable change index scores (Lovell, personal communication, 2005). ImPACT 2.0 was the version used in this study as research commenced prior to the release of ImPACT 3.0. ImPACT 2.0 consists of 6 individual test modules, modeled on traditional neuropsychological tests, measures aspects of cognitive functioning including attention, memory, reaction time and processing speed, and includes a clinical history and post concussion scale (Iverson, Lovell & Collins, 2002a). The report generates composite scores for Verbal and Visual Memory, Processing Speed, Reaction Time and a Symptom Scale score.

Test-retest intervals have shown stability co-efficients at a level higher or comparable with similar traditional neuropsychological tests (Iverson, Lovell & Collins, 2003). An intraclass correlation (ICC) has been conducted by Pardini and Lovell (2005), which showed high ICC values for the reaction time and processing speed composites, a relatively high value for visual memory and a somewhat lower value for verbal memory. These values were all higher than those provided by other concussion assessment measures (Pardini & Lovell, 2005). Validity studies have shown the test's ability to distinguish injured from uninjured controls, most particularly on the memory and postconcussion symptoms scale (Iverson, Lovell & Collins, 2002b). The validity of the processing speed and reaction time composites have also been investigating by establishing a correlation with the Symbol Digit Modalities Test, a traditional test used routinely in sport concussion research (Iverson et al., in press).

Reliable Change Indices (RCIs) have been calculated from test-retest studies for the .80

confidence level, although Iverson, Lovell & Collins (2003) acknowledge some limitations to the external validity of this study, suggesting further studies using more homogenous samples are needed, which are tested over varying time intervals. Also available for comparative purposes, are ImPACT US normative ranges for high school boys (ages 13-15 years and 16-18 years) and high school girls (ages 13-18 years) as well as and university students developed by Iverson et al. (2002a). (Further detail on the normative ranges is included in the methodology section, p.28). ImPACT is being used for an extended research programme on South African rugby union, (of which the present research study forms a part), being currently conducted by the Rhodes University National Sport Concussion Institute (NSCI). ImPACT has impressed as a programme with an extensive research base in respect of studies concerning reliability and validity. Furthermore, it is avaliable for research by neuropsychologists in South Africa because interpretation is not web-based. The ImPACT report generates results on a wider range of cognitive functions than Cogsport and the Concussion Resolution Index. In addition, local research with ImPACT has yielded initial RCIs and normative ranges specific to South African high school athletes in the 16 - 18 year age range (Shuttleworth-Edwards, Radloff, Whitefield & Mitchell, 2005), which will be incorporated into the present study.

1.5 Return to Play Protocol

As part of the rehabilitation programme, the Vienna Statement (2001) outlines: "Important principles state that the athletes be completely asymptomatic and have normal neurological and cognitive evaluations before the start of the rehabilitation programme" (p.8). Return to play protocol follows with a careful stepwise progression of exercise with the athlete only progressing to the next level when completely asymptomatic (Aubrey et al., 2002; McCrory et al., 2005). With more specifity to the general guidelines, the recent Prague Statement (2005) suggests that, in the case of 'simple' concussion, the asymptomatic athlete (after a minimum rest of 24 hours), may begin a graded programme of exertion, with a return to full contact training after medical clearance (minimum of 5 days post injury). Cases of complex concussion may require further medical attention and neuropsychological assessment (McCrory et al., 2005). As discussed earlier, an apparent shortcoming of the Prague Statement

(2005) is that the necessity for utilising neuropsychological assessment to identify persistent neurological deficits is not included in the Prague management and return-to -play recommendations. Rather, brief sideline tests and symptom checks alone are indicated for seemingly uncomplicated concussion with the apparent danger, however, that subtle neurocognitive deficits may go undetected resulting in players returning to play before complete recovery has taken place.

1.6 The Young Athlete

Based on participation levels, the largest group of athletes at risk for sustaining a concussion are at high school level or younger (Lovell et al., 2003). Numbers of adolescent athletes competing in contact sports and at risk for sustaining concussion, have been estimated from about 1.25 million in the United States alone (Lovell et al., 2003). There has been a paucity of published research in this area, with almost all research focusing on collegiate and professional athletes (Lovell et al., 2003). Recent neuropsychological studies aimed at high school athletes sustaining concussion (Collins, et al., 2003; Lovell et al., 2004) have focused on school sports such as American football, soccer and hockey. From their 1999 study, Powell and Barber-Foss estimated the national annual frequency of MTBI among high school athletes to be 62 816, with 63% of cases occurring in American football. 15 - 20 % of American high school football players sustain a concussion annually (Echemendia et al., 2001). Rugby Union, the variety of rugby football played in South Africa at all age levels, has been shown to be even more susceptible to incidences of concussion than American football (see review by Shuttleworth-Edwards et al., 2004). Amongst high school rugby players, the incidence of concussive injuries has been estimated at 2.3 (range 0 – 7) during their school playing years (Shuttleworth-Edwards et al., 2004). During a single rugby season at a South African high school, Nathan et al. (1983) found that concussion was the single most common injury, accounting for 12.1% of all rugby injuries.

1.6.1 Differences in child and adult concussion

1.6.1.1 Pathophysiological. The lack of research focusing on adolescent concussion is particularly alarming as the majority of the deaths from Second Impact Syndrome (SIS) have come from high school athletes, suggesting greater vulnerability to severe injury in children and young adults (Lovell et al., 2003). In cases of severe brain injury in children and adolescents, prolonged cerebral edema, delayed dysautoregulation and improved cortical plasticity have been found in comparison to severely injured adults (Grindel et al., 2001). McKeever & Schatz, (2003) draw attention to the possibility that concussive injury to the developing brain may cause temporary or permanent impairment to this plasticity. "Increased susceptibility to concussion in children and adolescents has been attributed to decreased mylination, a greater head-to-body ratio, and thinner cranial bones, all of which provide less protection to the developing cortex" (McKeever & Schatz, 2003, p.5).

1.6.1.2 Neuropsychological. The cognitive assessment of children is difficult due to the fact that the brain is cognitively maturing during childhood (McCrory et al., 2004). This may mean that the child is more vulnerable to the impact of the head injury because the injury may disturb the process of neuronal maturation (McCrory et al., 2004). Due to the process of maturation children may need to undergo regular baseline testing (possibly at 6 month intervals up to the age of about 16 years), unlike adults whose cognitive functioning is largely stable over time (McCrory et al., 2004). (In the absence of recent baseline scores, normative data, such as that developed by ImPACT is able to offer general management guidelines). While children, like adults, show a reduced cognitive performance following a concussion, differences in cognitive recovery rates have been found (Field et al., 2003). Specifically, after mild concussion, high school football and soccer participants, when compared with matched control subjects, had significant memory impairment at least 7 days after injury, while adult college football and soccer athletes had significant memory deficits only within the 48 hours to 5 days after injury (Field et al., 2003). Consequently there is a concern that the current guidelines, most of which assume a standard implementation for all age groups, may send the high school athlete back before full recovery has taken place (Field et al., 2003).

1.6.1.3 Management protocol

At present there is no validated management protocol specifically developed for children. Sideline assessment measures such as the SAC or Maddocks questions, have not been validated with a child population (McCrory et al., 2004). Growing recognition of the neurophysiological differences between adult and child athletes has been reflected in the additional management recommendations for the younger athlete found in the NATA Position Statement, (Guskiewicz et al., 2004) and the Prague Statement, (McCrory et al.,2005) namely: a conservative adult management strategy followed by stricter return to play guidelines. Both Statements recognise the important need for ongoing research in this area.

This overview of some of the key developments in the area of concussion indicates that while many issues are still unclear, findings thus far suggest that a cautious approach to concussion management is necessary, particularly amongst the younger age group. Adolescent athletes, suffering concussive injuries, appear to be particularly vulnerable for both transitory and potentially permanent cognitive deficits and even death in rare cases. Much research is needed, particularly in the area of adolescent concussion where few studies have been conducted. Results from the recently developed computerised neuropsychological tests suggest that these are the best suited cognitive assessment tools currently avaliable to manage a concussive injury safely, as well as to provide much needed insights into the nature of concussion. To the researcher's knowledge, there is no published research to date on computer-based assessments of South African high school athletes and no formal studies are presently avaliable using computer-based assessssment with the specific aim of investigating the utility of individualised baseline data relative to avaliable normative ranges.

Furthermore, published research on computer-based assessments have largely been group analyses rather than case-based research, and no case-based research of this nature has been accessed by the researcher in peer reviewed journals. The advantage of case-based research studies is that they "preserve the complexity of real-life situations far better than multivariate studies in which context and details of everyday clinical phenomena are easily obscured or lost altogether" (Edwards, Dattilio & Bromley, 2004, p. 590). In other words, individual differences and complexities can be taken into account and studied, rather than serving as possible excluding criteria for controlled group analyses. In studies on the sequelae following a concussion, such excluding criteria would typically be those individuals with prior history of psychological or neurological disorder, or record of scholastic difficulties such as a learning disability. However, it is vital that athletes with these histories be included for research purposes as an increased vulnerablity for injury among this population has been shown. Firstly, impulsivity, attentional impairment or distractedness could result in more dangerous play and secondly, if cognitive functioning is already compromised due to a neurological disorder, further brain injury could result in permanent impairment, i.e "the margin of cognitive reserve may be less in athletes with learning disorder and the threshold for manifesting morbidity may be lower" (Collins et al., 1999, p.968). Therefore, case-based research, such as the present study, is able to provide and accomodate for detailed, practical insights with regards the impact of a client's premorbid history, motivations and attitudes towards testing procedures, such as ImPACT. Ultimately, case-based research can result in the refinement, confirmation or questioning of theories or results gained from other methods, as well offering new insights which can be tested and expanded by similar case studies in the future (Edwards et al., 2004).

Chapter Two: METHODOLOGY

2.1 Participants

The participants consisted of schoolboy athletes from the two top rugby teams from one South African private high school that had consented to participate in the study. The athletes fell within the 16-18 year old age range and the baseline sample consisted of 31 participants. From incidence studies reviewed by Shuttleworth-Edwards et al., (2004) it was expected that 10-20% (3 – 8) concussions out of this cohort, would occur during the 2004 rugby season. The participants from the school would have had similar educational backgrounds. There were no exclusions, as individual differences in respect of psychiatric neurological criteria were a central feature of this study, i.e., how these differences might affect neurocognitive monitoring and recovery from a concussion. Standard procedure at the school rugby matches was the sideline presence of the St Johns Ambulance first aid team, medics from 911 Grahamstown and an ambulance to administer first aid and transport athletes to hospital or the school sanatorium as required. Standardised sideline questioning (such as the SAC) was not formally in use either by the coaches or medics. Athletes referred to the school sanatorium for observation were subsequently seen by a doctor. The doctor based his diagnosis on concussion guidelines by Kohler (2004) provided by the research coordinator, (see intro p.11) that was derived from the Vienna Statement, 2001. These guidelines include a list of typical symptoms and physical signs of concussion as well as the recommendations for medical management and return to play protocol based on the Vienna Statement (Aubry et al., 2001). In the opinion of the head of sport and school sanatorium sister, at the school in question, many concussions go unreported, despite asking all athletes after each game whether they are experiencing any concussive symptoms. Reasons suggested by the head of sport, for underreporting, were the athletes' reluctance to be excluded from sport due to sheer enjoyment of the game, as well as a desire not to let their team down. When athletes do seek assistance, it is typically a day or more later, after having experience unpleasant side effects such as vomiting or bad headaches. According to school policy, once an athlete has been diagnosed with a concussion he is immediately precluded from sport for a mandatory period of three weeks. During the rugby season, on the parameters described above, three athletes were suspected of having sustained a concussion on the field and were referred for follow-up testing, with one athlete being referred twice. (i.e. a total of four suspected concussions amongst the three athletes).The athletes ages ranged from 17 to 18 years; only one had a history of more than two concussions; one had a self-reported psychiatric history; one had a prior neuropsychiatric history and two reported medical conditions-one for asthma and sinusitis, the other for headaches. A summary of the identifying data of the athletes referred for post-concussion testing follows below:

Table 2: Identifying Data for participants sustaining concussive injuries

Id. Data	***Case 1 (N)***	***Case 2 (S)***	***Case 3 (M)***
Date of Birth	31/12/1985	13/07/1986	13/01/1986
Age	18	17	18
Years of education	11	11	12
Current sport	Rugby Union	Rugby Union	Rugby Union
Current team	2nd team	1st team	1st team and 2nd team
Primary position	fullback	flank	wing
Nr. of previous concussions diagnosed	3	1	1
Date of present injury/s	27/03/04; 19/06/04	15/05/04	31/07/04
Psychiatric History:	Depression, sleeping problems and PTSD in 2003	Neuropsychiatric: Mild Tourettes syndrome, ADD/Hyperactivity	None
Medical History	None	Asthma, sinusitis	Headaches

2.2 Assessment Instruments

2.2.1 Pre-Season Questionnaire: (see Appendix A) The pencil and paper biographical questionnaire especially designed for the purposes of the extended NSCI rugby research project. It consisted of identifying data, and relevant background information including a brief medical and psychiatric history and a concussion history.

2.2.2 ImPACT (Immediate Postconcussion Assessment and Cognitive Testing) Version 2.0. : The computerised ImPACT programme version 2.0 was used for this study. As indicated earlier, since the completion of data collection for this study last year, 2004, ImPACT version 3.0 has been released. Essentially however, the neuropsychological tests have remained unchanged, with the main difference in version 3.0 being the inclusion of certain data in the printed report such as the addition of percentile scores. ImPACT 2.0

consists of a demographic questionnaire including a brief medical history and a concussion history form, the neuropsychological test battery and a symptom questionnaire. The test battery consists of six individual modules which cover aspects of cognitive functioning sensitive to brain injury namely: attention, memory, reaction time and processing speed (Iverson et al., 2002a). Five composite scores were used in this study namely, Verbal Memory, Visual Memory, Reaction Time, Processing Speed and the Post concussion Scale:

> The Verbal Memory composite score represents the average percent correct for a word recognition test, a symbol number match task and a letter memory task with an accompanying interference task. The Visual Memory composite score represents the average percent scores for two tasks: a recognition memory task that requires the discrimination of a series of abstract line drawings and a memory task that requires the identification of a series of illuminated X's or O's after an intervening task. The Reaction Time composite score represents the average response time (in milliseconds) on a choice reaction time, go/no-go task, and the previously mentioned symbol match task. The Processing Speed composite represents the weighted average of three tasks that are done as interference tasks for the memory paradigms (Iverson, Lovell et al., 2003, p. 461).

The Impulse Control composite score has not been included in this study as it is still undergoing further validation and reliability studies. The Postconcussion Symptom Scale consists of 22 commonly reported symptoms, scaled from 0 - 6 (Iverson, Lovell et al., 2003). (A selection of key reliability and validity results to date appear earlier in the literature review, p.16.)

ImPACT: administration and scoring: As the test battery is computer-based it is possible to evaluate a group of athletes simultaneously in a school laboratory (Lovell & Collins, 2002). The test is administered by clinical neuropsychologists, certified trainers or physicians familiar with the administration procedures (Iverson, Gaetz, et al., 2003). For this study, administration of the baseline tests were co-ordinated by the NSCI research co-ordinator and the present researcher. Subsequent follow-up tests were conducted by the present researcher. The computer programme includes automatic and immediate scoring of tests and the generation of a report showing a detailed break down of scores as well as overall composite scores (Lovell & Collins, 2002)). Interpretation of scores is possible using reliable change indices and classification ranges derived from normative data.

The normative tables developed by Iverson et al. (2002a) for high school students is based on a total of 545 adolescents from 13 to 18 years. Exclusions were applied to any subjects who self-reported some history of education-related problems such as: any past learning problem (reading, maths or spelling), ADHD or special education placement.This sample was sorted by gender and age group comparisons which resulted in the formation of three groups: boys from 13 to 15 years, boys from 16 to 18 years and girls from 13 to 18 years. Percentile ranks were assigned to correspond to the natural distribution of scores which were in turn utilised to create the upper and lower limits of classification ranges (commonly used in cognitive assessment) for each cognitive composite score. These classification ranges are based on the following percentile rankings: Impaired < 2; Borderline 3 - 9; Low Average 10 - 24; Average 25 - 75; High Average 76 - 90; Superior 91 - 98; Very Superior > 99 (Iverson et al., 2002, p. 4). Recently, normative data for South African high school boys in the age range 16 to 18 years have been developed by Shuttleworth-Edwards et al. (2005) using the same methodology as described above. An additional exclusion criteria was applied to the South African sample however, namely any individual with a history of more than one concussion. A comparison of the **ImPACT cognitive composite normative ranges** for US and SA high school boys from 16-18 years appears below in Table 3. These cognitive composite ranges show a similarity of results with the exception of i) the reaction time which is marginally slower for the SA versus US sample across all categories and ii) processing speed where the cut-off point for the impaired range is substantially lower for the SA sample compared to the US sample.

Table 3. A comparison of United States and South African cognitive composite normative ranges for ImPACT for high school boys in the 16-18 year age range, with classification categories of performance based on percentile rankings.

	Verbal Memory		**Visual Memory**		**Processing Speed**		**Reaction Time**	
	US	**SA**	**US**	**SA**	**US**	**SA**	**US**	**SA**
Impaired	< 68	< 70	< 51	< 52	< 26.4	< 15.1	> .74	> .77
Borderline	69 - 74	71 - 73	52 - 59	53 - 64	26.5 - 29.6	15.2 - 30.2	.73 - 64	.76 - 68
Low Average	75 - 79	74 - 80	60 - 70	65 - 70	29.7 - 33.6	30.3 - 32.8	.63 - 59	.67 - .62
Average	80 - 92	81 - 93	71 - 88	71 - 86	33.7 - 42.5	32.9 - 42.3	.58 - 50	.61 - .55
High Average	93 - 98	94 - 96	89 - 93	87 - 94	42.6 - 47.7	42.4 - 46.3	.49 - 47	.54 - .51
Superior	99	97 - 100	94 - 96	95 - 98	47.8 - 51.1	46.4 - 50.2	.46 - 43	.50- .47
Very Superior	100	100	97 - 100	99 - 100	> 51.2	> 50.3	< .42	< . 46

The classification of results on the **ImPACT Symptom Scale** using US percentile norms (Iverson et al., 2002a) is tabled below together with the SA percentile norms (Shuttleworth-Edwards et al., 2005). The classification ranges were devised by Iverson et al., (2002a) "to reflect raw score ranges and percentile rank ranges in the natural distribution of scores" (p. 21). The same method was used by Shuttleworth-Edwards et al., (2005) to devise a comparable range of raw scores using the SA percentile norms.

Table 4. Classifications and raw scores derived from US and SA samples of high school athletes for ImPACT Symptom Scale scores.

Classification	***Raw Scores US norms***	***Raw Scores SA norms***
Low - Normal	0	0 - 8
Normal	1 - 6	9 - 18
Unusual	7 - 13	19 - 33
High	14 - 21	34 - 43

Classification	*Raw Scores US norms*	*Raw Scores SA norms*
Very High	22 +	45 +

A substantial difference in the raw score ranges on the Symptom Scale can be observed between the two sets of normative ranges, that may be due to cultural differences between the two cohorts.

Reliable change indices (RCIs) have been calculated by Iverson, Lovell et al. (2003) to guide the interpreter of the test results in respect of the amount of change in scores that can be attributed to normal variability versus how much change indicates a significant decline and cognitive impairment. Iverson, Lovell et al., (2003) have produced a quick guideline for reliable change at the 80% confidence level using a sample of 56 adolescents and adults. Their sample included males and females with an average age of 17.6 years (SD = 1.7, range = 15-22). The average retest interval was 5.8 days (median = 7, SD = 3, range = 1 - 13). A South African developed set of RCI's were developed on a sample of 145 school boy athletes in the 16-18 year old age range, with the test-retest interval based on a pre-post-season 6 to 7 month interval (Shuttleworth-Edwards et al., 2005).

Table 5. The US and SA Reliable Change Indices (RCIs) for ImPACT for the 80% confidence interval.

Composite	*US*	*SA*
Verbal memory	9 points	13 points
Visual memory	14 points	16 points
Reaction Time	0.06 s	0.08 s
Processing Speed	3 points	7 points
Symptom Scale	10 points	16 points

It can be seen above that the SA RCIs allows for a wider margin of normal variability that may be due to the methodological difference in the test-retest interval between the two studies. The longer 6 to 7 month interval in the SA study compared with only a 6 day interval in the US study, may have resulted in the greater allowance for 'normal' variability in the SA sample.

2.3 Procedures

Pre-season:

1) Consent from the schools was obtained from the headmaster via an informational interview conducted by the NSCI research co-ordinator (see Appendix B). As most of the athletes involved were boarders, the school, in *locus parentis*, granted permission for their involvement. For the small number of day-boys, copies of information were sent to their parents on behalf of the headmaster (see Appendix C1), as well as withdrawal forms in the event that permission for participation be declined (see Appendix C2). No withdrawals were received. Information and voluntary pupil consent forms were administered at the time of testing to those schoolboys permitted to take part (see Appendix D).

2) An informational talk was delivered by the NSCI research co-ordinator to the participants regarding the nature of concussive injuries and the value of neuropsychological testing for concussion management. Each participant was then issued with information sheets, a Pre-Season Questionaire and consent sheets. After an explanation of the forms and a time for questions, the participants signed the consent form and completed the Pre-Season Questionnaire. The participants then completed the baseline version of the ImPACT programme in the school computer laboratory in groups of 15-16 athletes per session, which were administered by the NSCI rearch co-ordinator and present researcher.

Post-injury:

The *general* follow-up procedure was as follows, while individual differences to these procedures are detailed under each separate case study report):

1) The researcher was informed of a concussive injury via the coach or school sanatorium sister. The athlete was then seen within 36 hours at the Rhodes Psychology Clinic. Information regarding the nature of the injury was gained from the athlete, the coach or referee who witnessed the injury, the doctor attending to the athlete, and the school sanatorium sister. The post-concussion version of the ImPACT computer programme was then administered.

ii) Subsequent testing with ImPACT was arranged at intervals of approximately 5 days until the athlete's scores had reached at least baseline level or displayed general recovery and the postconcussion symptoms had resolved. In certain cases school holiday breaks or other school commitments caused these intervals to be extended.

Post-season:

A post-season follow-up test using ImPACT was conducted.

2.4 Data Analysis

1. For each concussion, the ImPACT cognitive test data, derived at baseline and over the recovery period, were tabulated and graphically represented. These were then descriptevly compared using i) US and SA RCIs to substantiate any significant post-concussive decline from baseline levels, and ii) the US and SA normative ranges from impaired to superior levels to monitor changes in performance between baseline and post-concussion scores that in turn are evaluated against the expected performance ranges of the athlete, based on his scholastic history. A decline was suggested by a lowered score on the Verbal and Visual Memory and Processing Speed composites and a higher score for the Reaction Time and Symptom Scale (reflecting slowed time and an increase in symptoms respectively). In addition, the progression and decline of each ImPACT score, namely Verbal Memory, Visual Memory, Processing Speed, Reaction Time and the Symptom Scale score, over the test occasions, are graphically represented in the form of a bar graph for each case of concussion. Declines on the graphs are denoted by lowered bars for Verbal Memory, Visual Memory and Processing Speed, and by higher bars for Reaction Time (i.e. slower) and for Symptom Scale (more symptoms reported).

2. For the purpose of this research, the analysis of the Impact Symptom Scale Score was undertaken by delineating the 22 symptoms from the Postconcussion Symptom Follow-up Questionnaire under the following categories: *physical (with 17 possible items), cognitive (with four possible items) and emotional symptoms (with five possible items).* The *physical* symptoms include: 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, numbness or tingling, visual problems (double vision or blurring etc.), speech problems. The *cognitive* symptoms include: feeling slowed down, feeling mentally foggy, difficulty concentrating, difficulty remembering. The *emotional* changes include: irritability, aggression, sadness, nervousness, feeling more emotional. For each concussion, the follow-up symptom profile on ImPACT derived over the recovery period was tabulated and descriptively compared with the individual's baseline symptom presentation in terms of the total symptom score and the actual symptom pattern in terms of the physical, cognitive and emotional categories delineated above.

Chapter 3: CASE STUDIES

Introduction

Three case studies involving four concussions are presented separately below. Each case is introduced with the athlete's concussion history comprising a description of the present concussion and any prior concussions. Other relevant history follows under the headings - medical, psychiatric and educational. The results section is divided into clinical observations and ImPACT test results, including cognitive tests and symptom score results. In order to monitor significant decline and recovery the individual test scores on ImPACT will be interpreted in relation to the US RCIs (Iverson, Lovell et al., 2003) , the SA RCIs (Shuttleworth-Edwards et al., 2005), the US normative ranges (Iverson et al., 2002a) and SA normative ranges (Shuttleworth-Edwards et al., 2005). These normative ranges have been developed from percentile scores and the commonly used classification ranges which are described earlier (see methodology section, p.28). For each individual case, ImPACT scores will be presented in table form and graphically represented. Significant declines identified by the US & SA RCIs are indicated with an asterix and bold type respectively. All data for each case will refer to this table unless a score falls outside the expected classification range, in which case reference will be made to Tables 3 and 4 (see methodology section, p. 28) covering all classification ranges for cognitive and symptom scores respectively. In each case the table of ImPACT results is followed by a second table detailing the reported symptoms for the ImPACT Symptom Scale score, which in turn is followed by a graphical representation of each cognitive composite and the Symptom Scale scores across each test occasion.

3.1 CASE STUDY 1

Concussion History

Present concussion: (27/03/04) N was diagnosed with concussion following an injury sustained during a rugby match. The coach reported that approximately 40 minutes into the match, N had been observed running full speed with the ball which he had then released over his head. Shortly afterwards N was seen lying on the ground where he lay motionless for about 30 seconds. The coach checked N's peripheral vision and coordination and inquired whether he was experiencing dizziness or seeing spots. As none of these signs or symptoms were reported present, the coach was uncertain whether N was, in fact, concussed. N was removed from the field on a stretcher. N's account of the injury was incomplete as he could only remember "bits and pieces" and had been told by others what had happened. He recalled feeling "different" and "disorientated" and behaving inappropriately on the side lines while he watched the remainder of the match. Afterwards he could only remember "patches" of the game. N did not report to the school sanatorium until the following evening. He had been sleeping excessively and had woken feeling faint and experiencing a headache. He was admitted to the sanatorium overnight with a concussion with loss of consciousness (LOC), amnesia, dizziness and a headache. The following day N was seen by a medical doctor who diagnosed a concussion with amnesia for 30 minutes and ongoing headache. The doctor reported that N was otherwise "neurologically fine, not impaired". N was precluded from sport for three weeks as per standard procedure at the school (see methodology section, p. 24). Concussion details completed for the ImPACT report indicated retrograde amnesia for 15 minutes, anterograde amnesia 15 - 30 minutes and confusion/disorientation for 30 minutes.

Prior concussion/s: (before 2000) There were some inconsistencies in N's reporting of prior concussions i.e. he had reported three prior concussions on the Pre-Season Questionnaire, but only two on the ImPACT concussion history screen. When asked to give details later, N only recalled two concussions which had occurred before 2000. No LOC was reported for these concussions, but some confusion and amnesia were present. The most recent concussion had occurred on the 13/03/04, only two weeks before the current injury: N had not reported it and had continued playing. N described being elbowed in the head, seeing black spots and feeling confused for 2-3 minutes. He had had a headache and had experienced fatigue for the remainder of the day. The following day his symptoms had resolved.

Other relevant history

Medical: N had an extensive medical file at the school sanatorium, consisting generally of minor ailments.

Psychiatric: N reported that he had experienced depression, Post-Traumatic Stress Disorder and sleeping problems in 2003. The sanatorium sister, however, could not confirm that N had had any of above difficulties. She stated that the general rule was that parents request the sanatorium to monitor medication, but she had not been informed of any problem by his parents. She did, however, report an ongoing history of behavioral problems and that there were also family problems. On one of the number of screens N completed for educational history (ImPACT educational history section), N indicated he had been diagnosed with ADHD. This discrepancy was only noted after the athlete was no longer available for consultation, so clarification was sought from the sanatorium sister. In her opinion N did not have ADHD; he had never been on Ritalin and there was no indication in his school medical file suggesting the diagnosis.

Educational: N was in his final year of school, Grade 12, at the time of testing, with no learning disorder confirmed, and generally achieved an overall C result (i.e. 60 - 70 %). His midyear results were: English (HG) - C, Afrikaans (HG) - C, Mathematics (SG) - D, History (HG) - B, Biology (HG) - C, Drama (HG) - B. A premorbid estimate of functioning based on these academic results suggested that N generally showed an average potential, although some B and D aggregates suggested a range of academic abilities.

Results: Baseline testing (12/03/04), and three post-concussion tests (29/03/04; 05/04/04; 25/05/04).

Clinical Observations

Baseline 12/03/04: During baseline testing in the school computer laboratories, it was observed that N and a friend were being talkative and did not cooperate with requests to take the test seriously.

N was co-operative during the follow-up testing sessions, but did fail to arrive for at least two of the scheduled appointments.

First post-concussion test 29/03/04: N complained of neck stiffness on the side of the injury and that he felt physically weak.

Second post-concussion test 05/04/04: In addition to the ImPACT test, N was given the WMS: Associate learning – immediate recall test and the Rey 15-item test of malingering as the school coach believed that N may be underperforming on the ImPACT tests in an attempt to be excluded from the upcoming rugby tour. Family difficulties were suggested as a possible motivating factor. However, neither of these tests showed any overt signs of malingering.

Third post-concussion test 25/05/04: N did not return promptly for a follow-up test after the school holidays and had played in two rugby matches prior to the retest.

ImPACT Test Results: These appear in Tables 6 and 7, and figs. 1.1-1.5 below

Table 6. Summary of the ImPACT test results for the baseline test and three post-concussion tests in comparison with the US and SA Normative Data for high school boys ages 16 - 18 years in the average range.

ImPACT scores	***B/line***	***29/03/04 (p-c 1)***	***05/04/04 (p-c 2)***	***25/05/04 (p-c 2)***	***US Norms average range***	***SA Norms average range***
Verbal Memory	80	71*	69*	69*	80 - 92	81 - 93
Visual Memory	74	**52***	63	69	71 - 88	71 - 86
Processing Speed	31.3	25.23*	32.38	30.75	33.7 - 42.5	33 - 42.6
Reaction Time	0.58	**0.70***	**0.66***	0.57	0.58 - 0.5	0.61 - 0.55
Symptom Scale	24	**45***	20	6	1 - 6	9 - 18

* Denotes significantly poorer performance relative to baseline scores using US RCIs
Bold type denotes significantly poorer performance relative to baseline scores using SA RCIs

Table 7. Self-reported postconcussion symptoms on the ImPACT Symptom Scale in the three categories at baseline and at the three post-concussion tests

Date of test	***Total score***	***Physical Symptoms***	***Cognitive Symptoms***	***Emotional Symptoms***
Baseline (12/03/04)	24	headache (1); dizziness (1); fatigue (2); trouble falling asleep (4); sleeping more than usual (4); sleeping less than usual (1); drowsiness (1)	feeling slowed down (1); feeling mentally foggy (1); difficulty concentrating (2)	irritability (1); sadness (3); nervousness (1); feeling more emotional (1)
First post-concussion test (29/03/04)	45	headache (1); nausea (1); vomiting (1); balance problems (2); dizziness (2); fatigue (3); trouble falling asleep (2); sleeping more than usual (3); sleeping less than usual (2); drowsiness (3); sensitivity to light (2); sensitivity to noise (3); numbness or tingling (2); visual problems (1)	feeling slowed down (3); feeling mentally foggy (3); difficulty concentrating (3); difficulty remembering (3)	irritability (1); sadness (1); nervousness (1); feeling more emotional (1);
Second post-concussion test (04/05/04)	20	headache (1); balance problems (2); dizziness (1); fatigue (3); sleeping more than usual (1); drowsiness (1); sensitivity to light (2); sensitivity to noise (1); visual problems (1)	feeling slowed down (2); feeling mentally foggy (1); difficulty remembering (2)	irritability (1); sadness (1)
Third post-concussion test (25/05/04)	6	sleeping more than usual (1); sleeping less than usual (1); drowsiness (1)	feeling mentally foggy (1); difficulty concentrating (1)	feeling more emotional (1)

In graphical representation, ImPACT results at baseline and at the three post-concussion tests are shown below for the cognitive composites Verbal Memory, Visual Memory, Processing Speed, Reaction Time and for the Symptom Scale scores.

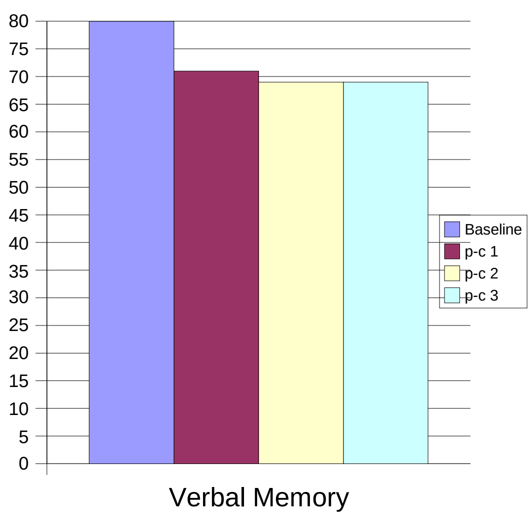


Fig. 1.1 Scores for the Verbal Memory composite at baseline and at the three post-concussion tests (p-c 1 to 3)

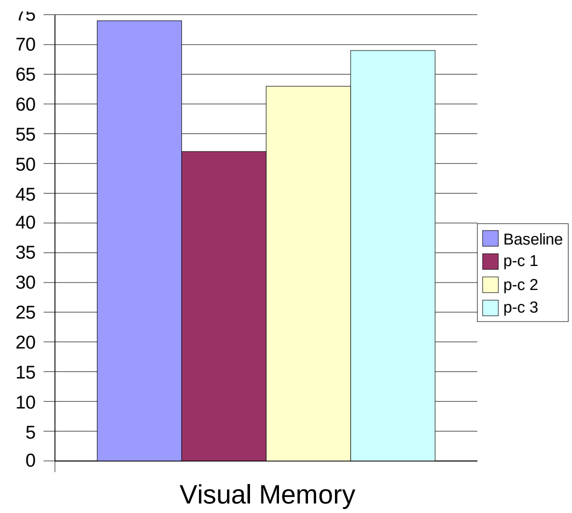


Fig. 1.2. Scores for the Visual Memory composite at baseline and at the three post-concussion tests (p-c 1 to 3

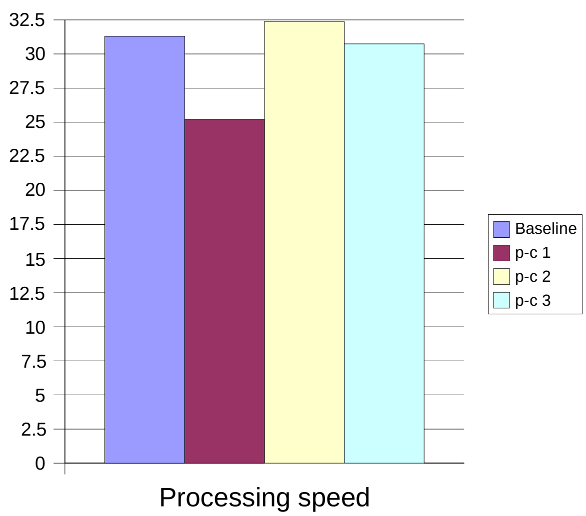


Fig. 1.3. Scores for the Processing Speed composite at baseline and at the three

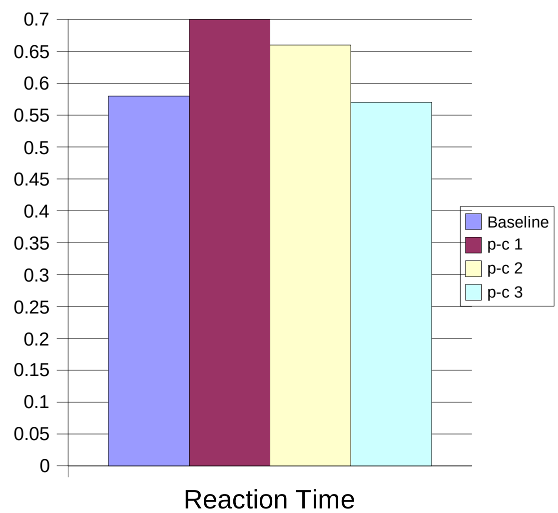


Fig. 1.4. Scores for the Reaction Time composite at baseline and at the three

post-concusssion tests (p-c 1 to 3) **post-concussion tests (p-c 1 to 3)**

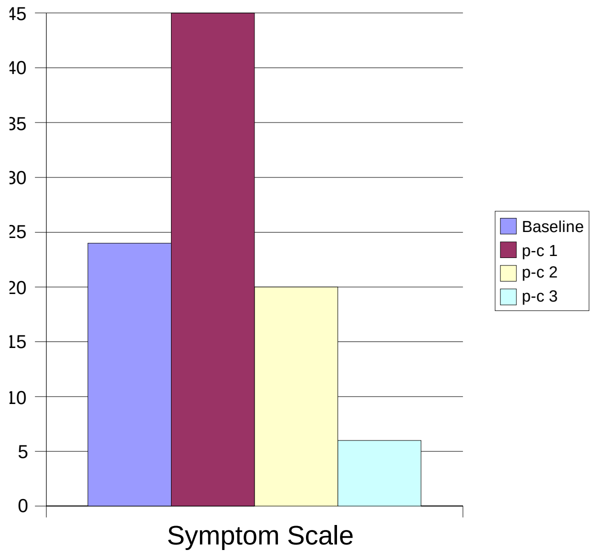


Fig. 1. 5. Scores for the Symptom Scale score at baseline and at the three post-concussion tests (p-c 1 to 3)

Analysis of Test Results

Baseline assessment 12/03/04. Three of N's baseline cognitive composite scores, namely Verbal Memory, Visual memory, Reaction Time scores fell in the lower limits of the average range using both the US and SA normative ranges, while his Processing Speed score fell in the low average range (see Table 3, p.28). These cognitive test results appear to be marginally lower than expected, given N's scholastic record suggesting an average ability. There is also the query re N's unconfirmed ADHD which could have been a contributing factor regards the lower Processing Speed score (Calhoun & Temple, 2004). It is also possible that N's apparent distractedness observed during the testing procedure, could have resulted in a less than optimum baseline performance. The Symptom Score result fell in the very high range using the US normative ranges, and within the unusual range using the SA normative ranges. A variety of symptoms were ranked, covering all categories (see Table 7) with relatively high scores given to sleep difficulties (4) and sadness (3). An apparent tendency to somatise was evident from N's extensive school sanatorium file and appears to be reflected here in his above normal Symptom Scale result.

The *first post-concussion test (29/03/04; 2 days after injury).* Significant decline or substantial decline, relative to his baseline scores, was found for all cognitive composite scores using both the US and SA RCIs and, commensurate with this, all results fell outside the expected average US and SA normative ranges in the direction of poor performance (see Table 6). Specifically, using the US RCIs a significant decline on baseline performance was found across all four cognitive composite. Using the SA RCIs, significant decline was evident on the Visual Memory and Reaction Time composites, while the Verbal Memory and Processing Speed composites bordered on the level of significant decline. The US and SA normative ranges similarly reflected these declines, with scores falling in the borderline and impaired ranges (see Table 3, p.28); Verbal Memory and Reaction Time scores both fell in the borderline (lower limit) range using US and SA normative ranges; Visual Memory score fell in the borderline range (US normative ranges) and impaired range (SA normative ranges), while Processing Speed score fell in the impaired range (US normative ranges) and borderline range (SA normative ranges). The Symptom Scale scores showed significant change in the direction of increased symptomology using both US and SA RCIs and fell in the very high range using both US and SA normative ranges. In particular, self-reported physical and cognitive symptoms on this scale had increased in number and intensity since the baseline test. Some conflicting results were noticed under physical symptoms, namely both sleeping more than usual (3) and sleeping less than usual (2). This could merely be a mistake or could possibly reflect an attempt to inflate the Symptom Scale score. Despite this inconsistency, the overall decline in cognitive composite scores and high symptom score is suggestive of a concussive injury using all interpretative methods.

The *second post-concussion test (05/04/04; 9 days after injury).* The cognitive composite scores showed some improvement since the last time of testing, with the exception of the Verbal Memory score, which had dropped two points and remained significantly lower than the baseline score using the US RCIs and bordered on the level of significant decline using the SA RCIs. In terms of the US normative ranges, the Verbal Memory result dropped to the lower limit of the borderline range and from the borderline to impaired range using the SA normative ranges. The Visual Memory score no longer showed significant decline, but was still well below baseline levels. Using US normative ranges, the Visual Memory score showed improvement since the previous assessment, moving from borderline to low average (lower limit) range and from impaired to borderline range using the SA normative ranges. The Processing Speed result, which had shown significant decline at the previous time of testing, had improved on the baseline score, and moved to the upper limits of the low average range using both normative ranges. With the advantage of the baseline score for Processing Speed (a low average result) it would appear that a return to baseline range had been reached for this composite. However, due to N's poor test taking attitude, it is possible that the baseline score did not reflect an optimum performance and that the score could possibly still be showing a slight decline. An analysis in terms of normative ranges also indicated that recovery was incomplete, with N's scores not yet in the expected average range. Reaction Time still showed significant decline relative to his baseline performance using both US and SA RCIs and fell in the borderline range using the US normative ranges. In terms of the SA normative ranges, however, an improvement was observed with the score moving from a borderline ranking to low average range (lower limits). The Symptom Scale score also improved, moving from the very high range to the high range in terms of the US normative ranges, and from the very high range to the unusual range using the SA normative ranges. N continued to report a number of symptoms across the categories, but overall their grading shows a drop in intensity since the previous time of testing. Overall, the combination of declined and improved scores suggested a partial, yet incomplete recovery at this assessment.

Third post-concussion test (25/05/04, 8 weeks 2 days after injury). Using all interpretative methods, overall improvement on all scores was noted, since the previous follow-up, with the exception of the Verbal Memory composite which continued to show impairment using both US and SA RCIs and both normative ranges. The Visual Memory score showed improvement since the last time of testing, but continued to fall below the baseline score. In terms of the US normative ranges, this score continued to fall in the low average range, but had improved from borderline to low average (upper limits) range using the SA normative ranges. The Processing Speed score had declined slightly since the previous time of testing, and now fell in the lower, rather than the upper limits of the low average range using both normative ranges. Reaction Time showed good recovery using all methods, no longer showed significant decline and had improved on the baseline score. Using both normative ranges, the Reaction Time result now fell in the average range. The Symptom Scale showed a significantly improved score relative to baseline and improved from the high range to the normal range (upper limits) using the US normative ranges and from the unusual range to the low-normal range using the SA normative ranges. There was an overall decrease in the number of symptoms rated, none of which was ranked higher than a '1'.

In sum, at the third follow-up, only two ImPACT cognitive composites, Reaction Time and the Symptom Scale, showed a return to baseline levels. However, a perusal of the results (see figs. 1.1-1.6) highlights the seeming overall recovery and general return to baseline levels occurring on most scores, with the exception of the Verbal Memory composite which displayed persistent deficit. After the initial decline on the Visual Memory composite at the first follow-up, a steady progression towards baseline levels can be seen, despite not yet reaching baseline levels, at the third follow-up. The Processing Speed score, however, had already passed baseline levels at the second follow-up, which seemed to suggest that the slight decline at the third follow-up test was a minor fluctuation and that recovery had in fact returned for this composite. A steady improvement towards and marginally past baseline level can also be observed for the Reaction Time composite. However, as mentioned earlier, it is possible that the baseline scores are slightly lower than they could have been, which raises the possibility that a subtle overall cognitive decline continued to linger across the composites. A possible reason for the protracted recovery could be the earlier concussion sustained two weeks before the present concussion. It seems possible that when the present concussion occurred, the brain was still in a slightly vulnerable condition as a result of the previous injury. Subsequently when the present injury was sustained, a more severe injury took place resulting in the persisting cognitive deficits recorded at this third follow-up. In terms of the Brain Reserve Capacity Theory (BRC), injury to the brain can have the effect of lowering the brain reserve capacity and consequently increasing vulnerability to functional impairment, namely cognitive deficits. In addition, if N's report of ADHD was correct, this could have been an added vulnerability factor, further lowering the protective threshold.

A comparison of the interpretations of the test results using both the US and SA RCIs and US and SA normative ranges showed very similar results for the Verbal and Visual Memory and Processing Speed Composites across all test occasions. The advantage of having a baseline score to ascertain recovery was evident with the Processing Speed Composite where a return to baseline level was demonstrated on the second follow-up, (baseline score = 31.3; second follow-up score = 32.38). However, this score still fell below the expected average range in terms of the US and SA normative ranges which suggested an incomplete recovery. This discrepancy between analyses using baseline data versus normative ranges points to the possible limitations of using normative data alone that do not reflect subtle individual differences. However, given that N was not fully co-operative during baseline testing, and the fact that his baseline scores were marginally lowered relative to the US and SA normative ranges, raises the possibilty that persistent decline could be in evidence. For the Symptom scale, the inflated baseline data, relative to the SA and US normative ranges, was potentially important in this case: On the second follow-up N was reporting no more symptoms than at baseline, (although this score was still higher than normal ranges for both US and SA databases), and by the third assessment his scores had dropped markedly in comparison to baseline, falling in the normal range in terms of the US normative ranges and in the low-normal range using SA normative ranges. This pattern of scores suggested that N could have been underreporting symptoms, an observation that would not have been clearly evident by using normative ranges alone, particularly when using the US normative ranges.

3.2 Second reported concussion for CASE 1

Concussion history

Present concussion: 19/06/04 Following a weekend rugby match, N reported to the sanatorium on the 22/06/04 believing he had sustained a concussion after being hit on the head. Confusion arose when he subsequently denied being concussed. As the coach had not observed him being injured, he was unable to confirm whether the injury had, in fact, taken place. N arrived reluctantly for testing four days post-injury. He described being hit on the forehead and feeling dizzy for a few seconds with no other symptoms experienced.

Prior concussions: The history for prior concussions has already been reported, namely: two before 2000, 13/03/04 (unreported), and 27/03/04. This brought the total number of concussions sustained to at least four, excluding the presenting injury.

Results: Baseline testing (12/03/04), one early follow-up test (23/06/04) and a later follow-up test at post-season (13/09/04).

Clinical Observations

First post-concussion test 23/06//04: The doctor, coaches and sanatorium sister were informed that N's ImPACT results were suggesting a concussive injury and that he should be advised against returning to play until his scores improved. At his mother's request N was sent for a CT scan the following day, despite communications from the researchers to the coach that CT scans are not sensitive to concussive injuries. Unsurprisingly, the CT result showed no abnormality. Despite the researcher's and doctor's recommendations, N played in a rugby match that weekend. N did not arrive for his scheduled appointments the following week prompting the researcher to communicate to the coach, that without the willing participation of the athlete it was difficult to monitor his progress. It was decided not to schedule any further appointments, but it was emphasized that the researcher was ready to resume testing should the athlete wish to continue. N took part in a rugby tour at the end of the term, despite concern from the doctor, coach and the researcher. His mother wrote a letter in this regard, giving permission for N to play and confirming that she was aware of the concerns of all involved.

Second post-concussion test 13/09/04: In the interim period between the last time of testing N had played in a number rugby matches, including a rugby tour and had a one month school vacation. N confirmed that he had sustained three concussions during the rugby season that year at the postseason test.

ImPACT Test Results: These appear in Tables 8 and 9 and figs. 1.6-1.10 below.

Table 8. Summary of the ImPACT test results for the baseline test and at the two post-concussion tests in comparison to US and SA Normative Data for high school boys ages 16 - 18 years in the average range.

ImPACT Scores	***B/line***	***23/06/04 (p-c 1)***	***13/09/04 (p-c 2)***	***US Norms average range***	***SA Norms average range***
Verbal Memory	80	69*	79	80 - 92	81 - 93
Visual Memory	74	59*	82	71 - 88	71 - 86
Processing Speed	31.3	25.0*	31.75	33.7 – 42.5	33 - 42.6
Reaction Time	0.58	0.64*	0.59	0.58 – 0.5	0.61 - 0.55
Symptom Score	24	11	6	1- 6	15 - 16 SD= 13-15

* Denotes significantly poorer performance relative to baseline scores using the US RCIs
Bold type denotes significantly poorer performance relative to baseline scores using the SA RCIs

Table 9. Self-reported postconcussion symptoms on the ImPACT Symptom Scale in three categories, at baseline and at the two follow-up tests

Date of testing	***Total score***	***Physical Symptoms***	***Cognitive Symptoms***	***Emotional Symptoms***
Baseline (12/03/04)	24	headache (1); dizziness (1); fatigue (2); trouble falling asleep (4); sleeping more than usual (4); sleeping less than usual; drowsiness (1)	feeling slowed down (1); feeling mentally foggy (1); difficulty concentrating (2)	irritability (1); sadness (3); nervousness (1); feeling more emotional (1)
First post-concussion test (23/06/04)	11	fatigue (2); sleeping more than usual (1); drowsiness (2);	feeling slowed down (1); difficulty concentrating (2); difficulty remembering (2)	irritability (1);

Date of testing	*Total score*	*Physical Symptoms*	*Cognitive Symptoms*	*Emotional Symptoms*
Second post-concussion test (13/09/04)	6	headache (1); fatigue (1); trouble falling asleep (1);	feeling mentally foggy (1); difficulty concentrating (1)	irritability (1);

In graphical representation the ImPACT results at baseline and at the two post-concussion tests are shown below for the cognitive composites: Verbal Memory, Visual Memory, Reaction Time and Processing Speed and for the Symptom Scale scores.

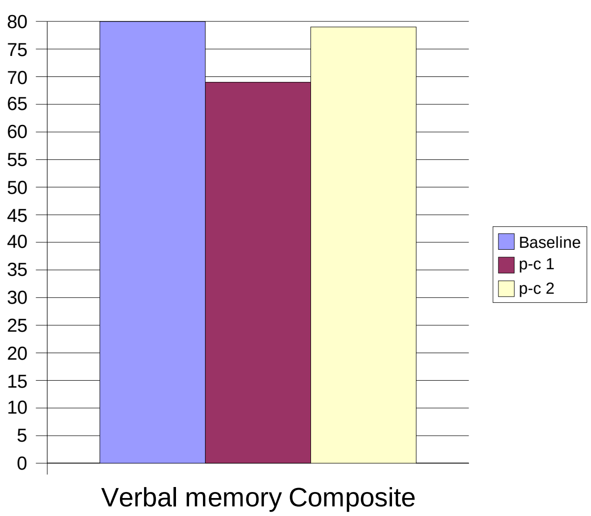


Fig. 1.6 Scores for the Verbal Memory Composite at baseline and at the two post-concussion tests (p-c 1 and 2)

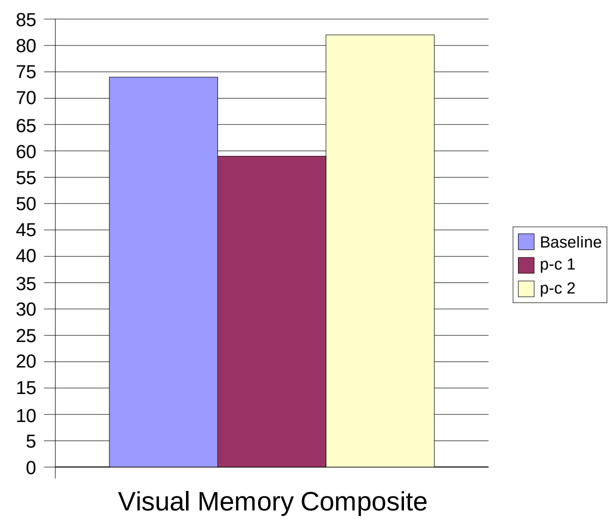
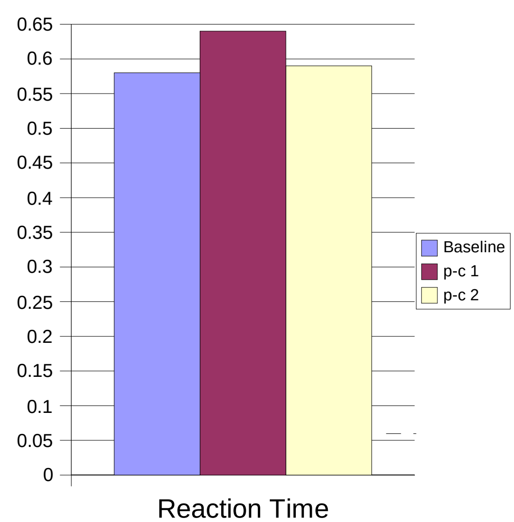


Fig. 1.7 Scores for the Visual Memory Composite at baseline and at the two post-concussion tests (p-c 1 and 2)



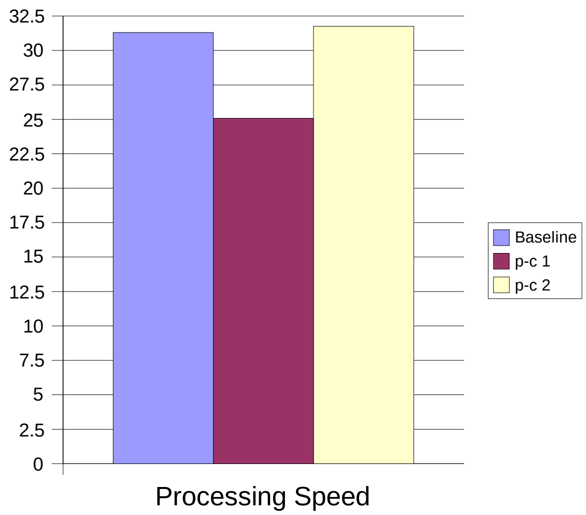


Fig. 1.8 Scores for the Processing Speed Composite at baseline and at the two post-concussion tests (p-c 1 and 2)

Fig. 1.9 Scores for the Reaction Time Composite at baseline, at the two post-concussion tests (p-c 1 and 2)

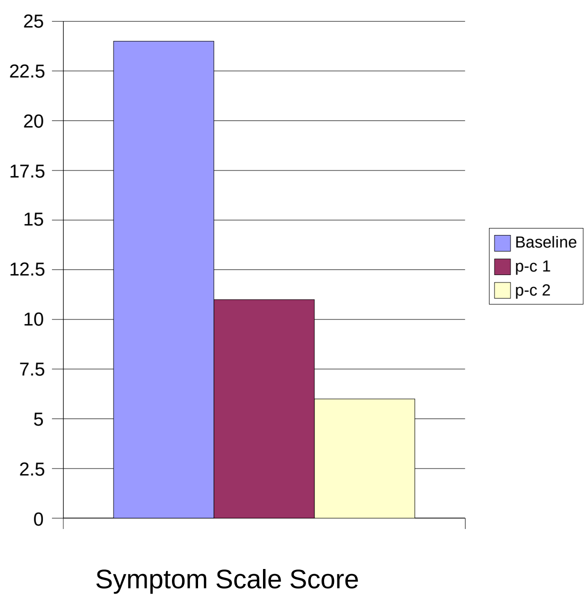


Fig. 1.10 Scores for the Symptom Scale at baseline and at the two post-concussion tests (p-c 1 and 2)

Analysis of Test Results

The *first post-concussion test (23/06/04; 4 days after injury).* At this first post-injury test all of N's cognitive composite scores were markedly lower than his baseline scores and expected range of ability (see previous report and Table 8). Using the US RCIs, significant declines relative to baseline levels, were found on every cognitive composite score. Similar decline was evident using the SA RCIs where all composite scores bordered on the level of significant decline. An analysis using both sets of of normative data also showed a marked decline from the expected average ranges, as all the composite scores fell in the impaired and borderline ranges, with the exception of Reaction Time which fell in the low average range using the SA normative ranges (see Table 3, p.28). Specifically, the Verbal Memory score fell in the borderline range using the US normative ranges and in the impaired range using the SA normative ranges; the Visual Memory score fell in the borderline range using both normative ranges; the Processing Speed score fell in the impaired range using the US normative ranges and in the borderline range using the SA normative ranges and the Reaction Time score fell in the borderline range using the US normative ranges and in the low average range using the SA normative ranges. The Symptom Scale score however, showed significant improvement over the baseline score. N's Symptom Scale score fell in the unusual range using the US normative ranges, but in the normal range using SA normative ranges. The improved score for the Symptom Scale denoted by the RCIs and in respect of the normative ranges could suggest a rapid resolution of post-concussion symptoms. It seems more likely, however, that N was under-reporting symptoms at the post-injury follow-up given that he had attempted to deny that a concussive injury had occurred.

The indication of significant cognitive decline across the composites relative to N's baseline scores strongly suggests the possibility of a concussive injury. These cognitive declines can clearly be seen in figs. 1.6-1.9. On the basis of the lower than expected cognitive scores (falling well below the average range) a concussion would be also be suspected if using the both US and SA normative ranges alone. The average Symptom Scale score result however, did not reflect the characteristic increase of symptomology following a concussive injury, (as observed after N's first reported concussion) and seems best explained as a case of under-reporting or a rapid resolution of post-concussion symptoms.

The s*econd post-concussion test (post-season) (13/09/04):* These results showed a seemingly good recovery since the previous time of testing, generally returning to baseline levels in all modalities. Neither the US nor the SA RCIs revealed significant declines on any of the ImPACT composite scores. The Verbal Memory score fell just one point below the baseline score. Using both sets of normative data, the Verbal Memory result showed improvement moving from the borderline range (US normative ranges) and impaired range (SA normative ranges) to the low average range (upper limits). Without the advantage of the baseline score, it would not be possible to know that this score showed a return to baseline levels. Visual Memory, now exceeded the baseline level and this recovery was reflected in the improvement from borderline to average range using the normative ranges. Processing Speed moved up to the low average range using both norms - an improvement over the impaired (US normative ranges) and borderline (SA normative ranges) ranking obtained at the previous test. Only with the baseline score, however, could it be ascertained that this Processing Speed score indicated a marginal improvement on baseline level. Using the US normative ranges, the Reaction Time composite showed an improvement from the borderline range to the low average range (upper limits). Change was less evident using the SA normative ranges where the score remained in the average range. Again, the advantage of baseline information was seen as this post-season score is only 0.01s higher than the pre-season level. The Symptom Score continued to show a significant change in the direction of resolution when using both RCIs and showed improvement from the unusual to the normal range (upper limit) using the US normative ranges. In terms of the SA normative ranges a change from the normal to the low-normal range was recorded. Fewer symptoms were rated, none graded higher than a '1'. As there was no cognitive decline evident, and the rugby season was over, there was little reason to suspect an under-reporting of symptoms. Thus retrospectively, it would seem that as a consequence of completing numerous Symptom Scales over the past months, N had developed a more realistic self-appraisal of his own symptomology, in line with the average normative ranges.

In sum, N appeared to show a return to baseline levels at the post-season test on all cognitive composites and continued to show significant improvement on the baseline Symptom Scale score. However, if it is surmised that N's baseline scores were slightly lower than they should have been, only the Visual Memory composite showed a marked improvement relative to baseline scores. This could suggest a slight persistence of cognitive decline on the other three composites. If using normative data alone to interpret the post-concussion scores, it would be expected that most of N's composites would fall in the average range, however, using the US normative ranges three post-season scores fell in the low average range and only one in the average range, while using the SA normative ranges two scores fell in the average range and two in the low average range. Using normative range alone would therefore also have raised the possibility that N was showing signs of subtle, but persistent cognitive deficit. This deficit could be explained as the cumulative effect of his prior concussions. In total, it appeared that N had sustained a minimum of five concussive injuries during his school career, with three of these concussions occurring in the past rugby season. In terms of the concept of the BRC theory, (see pathphysiology section p. 9), it seems possible that a summation of the concussive injuries had effected a lowering of the margin of brain reserve capacity and threshold level. The aggregate effect of these concussions could be seen to be impacting on N's functional abilities, such that at the final post-season test, a subtle decline on Verbal memory, Processing Speed and Reaction Time composites still appeared to persist. An added factor which could hace contributed to e lowering of brain reserve capacity could have been the neuropsychiatric disorder, ADHD, although this was not confirmed to be present.

3.3 CASE STUDY 2

Concussion history

Present concussion: 15/05/04 The injury occurred within the first few seconds of the rugby game when S dived onto a player who had caught the ball. The player’s knee made forceful contact with S’s neck, below the ear. S recalled feeling dazed for about one minute and confused for a few seconds. He felt a tingling sensation like pins and needles in his hands and feet. No amnesia was reported. S sat off for the rest of the game and by the time the doctor arrived, was feeling better apart from a headache of the base of the skull on the left side. A diagnosis of concussion was uncertain at this stage. S spent most of Sunday sleeping at the school sanatorium, felt a bit unbalanced at times and had a slight headache. He reported to the sanatorium on Monday still feeling sleepy and complaining of a headache. He was seen by the doctor that morning, who decided to treat the injury as a concussion and precluded S from sport for the following three weeks. The doctor further reported that S said he felt heavy-headed, sleepy, tired and slightly hazy and it was apparent that he was getting flu.

Prior concussion/s: 2000 One previous concussion was reported which included confusion, but did not involve LOC or amnesia. Two rugby matches were missed as a result.

Other relevant history

Medical: Asthma and an ongoing sinusitis problem was reported in the sanatorium medical records.

Psychiatric: S consistently indicated throughout the testing procedures that he had been diagnosed with ADHD although this was not confirmed by the sanatorium medical records. However, at the final test he disclosed that he had recently been placed on Ritalin to assist his difficulites in concentration and attention for the forthcoming examinations. This seems to confirm the presence of a ADHD disorder. The school records did show, however, that S suffered from mild Tourette's Syndrome, but that he was not on any medication for this condition.

Educational: S was in his final year of school, Grade 12, at the time of testing, with a self-reported difficulty with concentration. He generally achieved an overall C result (i.e. 60 - 70%). His midyear results were: English (HG) - D, Afrikaans (HG) - F, Mathematics (SG) - C, Drama (HG) - B, History (HG) - C, Geography (HG) - C. A premorbid estimate of functioning in terms of these results placed S in the average range. However, the varied results across the subjects, suggested a range of strengths and weaknesses.

Results: Baseline (12/03/04), five subsequent follow-up tests (17/05/04; 28/05/04; 04/06/04; 23/06/04; 13/09/04).

Clinical Observations

Baseline 12/03/04: S was observed talking during the baseline testing procedure.

First post-concussion test 17/05/04: S was observed to be sniffing during testing. This symptom could be the result of allergy, flu symptom or a combination of both.

Second post-concussion test 28/05/04: S was still showing the effects of flu and sinusitis which had caused his testing time to be postponed.

Third post-concussion test 04/06/04: S complained of a headache during the time of testing, which was initiated by coughing. He was observed to be still sniffing during testing. As S's three week break from sport was complete, there was concern that he was returning to play before returning to his baseline score in all modalities, although it was difficult to ascertain whether this was due to his flu or complications arising from the concussion. As a result a letter was sent to the doctor and coach recommending a further medical check-up before S resumed play.

Fourth post-concussion test 14/06/04: The doctor sent S for an EEG and MRI scan as he was concerned about S's headaches. According to the doctor sinus headaches which can be precipitated by coughing, occur on the right side of the head, but it appeared that S was experiencing pain on the left side. S had also started receiving treatment for his sinus problems. S's scan results had been clear, but there were indications of extensive inflammatory changes within the paranasal sinuses. The sanatorium sister also reported that in her opinion, S's tic had become more pronounced since his concussion.

Fifth post-concussion test 13/09/04: S reported that his sinus problem had not improved and that he may need to undergo surgery. He was recently put on a mild dose of Ritalin to help with attention and concentration over the final examinations and disclosed that he had always battled to concentrate. S also reported that he takes medication for anxiety during exam time.

ImPACT Test Results: These appear in Tables 10 and 11 and figs. 2.1-2.5 below.

Table 10. Summary of the ImPACT test results for the baseline test and three follow-up tests in comparison to the US and SA normative data for high school boys ages 16 - 18 years in the average range

ImPACT scores	***Baseline***	***17/05/04 (p-c 1)***	***28/05/04 (p-c 2)***	***04/06/04 (p-c 3)***	***23/06/04 (p-c 4)***	***09/13/04 (p-c 5)***	***US Norms average range***	***SA Norms average range***
Verbal Memory	88	89	91	**69***	95	95	80 - 92	81 - 93
Visual Memory	80	90	84	81	80	85	71 - 88	71 - 86
Pro. Speed	33.2	**22.5***	**24.70***	**22.3***	28.9*	**25***	33.7 -42.5	33 - 42.6
Reaction Time	0.59	0.56	0.57	0.61	**0.77***	0.62	0.58 - 0.5	0.61 - 0.55

ImPACT scores	***Baseline***	***17/05/04 (p-c 1)***	***28/05/04 (p-c 2)***	***04/06/04 (p-c 3)***	***23/06/04 (p-c 4)***	***09/13/04 (p-c 5)***	***US Norms average range***	***SA Norms average range***
Symptom Scale	27	10	2	3	0	1	1 - 6	9 - 18

* Denotes significantly poorer performance relative to baseline scores using the US RCIs
Bold type denotes significantly poorer performance relative to baseline scores using the SA RCIs.

Table 11. Self-reported post-concussion symptoms on the ImPACT Symptom Scale in three categories, at baseline and at the five post-concussion tests

Date of Testing	***Total Score***	***Physical Symptoms***	***Cognitive Symptoms***	***Emotional Symptoms***
Baseline (12/03/04)	27	headache (1); dizziness (2); fatigue (3); trouble falling asleep (3); sleeping less than usual (2); drowsiness (2); numbness or tingling (1); visual problems (3)	feeling slowed down (1); feeling mentally foggy (1); difficulty concentrating (2); difficulty remembering (3)	irritability (2); nervousness (1);
First post-concussion test (17/05/04)	10	dizziness (1); sleeping more than usual (4); drowsiness (1); visual problems (1)	feeling slowed down (1); feeling mentally foggy (1); difficulty concentrating (1)	
Second post-concussion test (28/05/04)	2	trouble falling asleep (1); visual problems (1)		

Date of Testing	***Total Score***	***Physical Symptoms***	***Cognitive Symptoms***	***Emotional Symptoms***
Third post-concussion test (04/06/04)	3	headache (2); visual problems (1)		
Fourth post-concussion test (23/06/04)	0			
Fifth post-concussion test (13/09/04)	1		difficulty concentrating (1)	

In graphical representation, ImPACT results at baseline and the three post-concussion tests, are shown below for the cognitive composites: Verbal Memory, Visual Memory, Processing Speed and Reaction Time, and for the Symptom Scale scores.

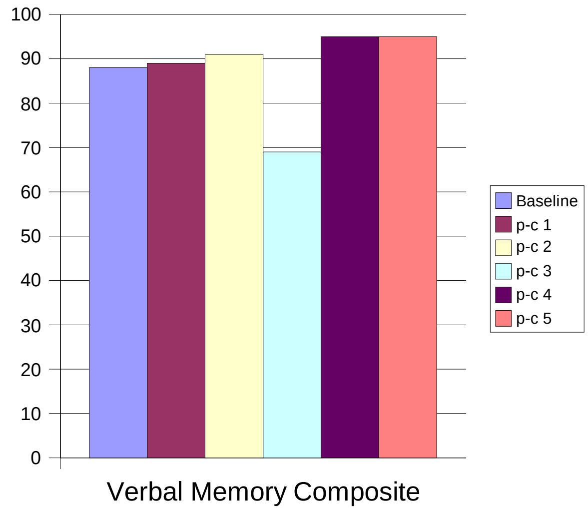


Fig. 2.1. Scores for the Verbal Memory Composite at baseline and at the five post-concussion tests (p-c 1 to p-c 5)

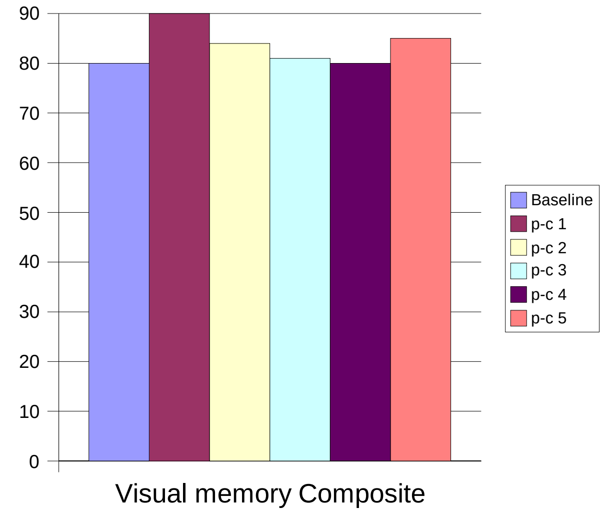


Fig. 2.2. Scores for the Visual Memory Composite at baseline and at the five post-concussion tests (p-c 1 to p-c 5)

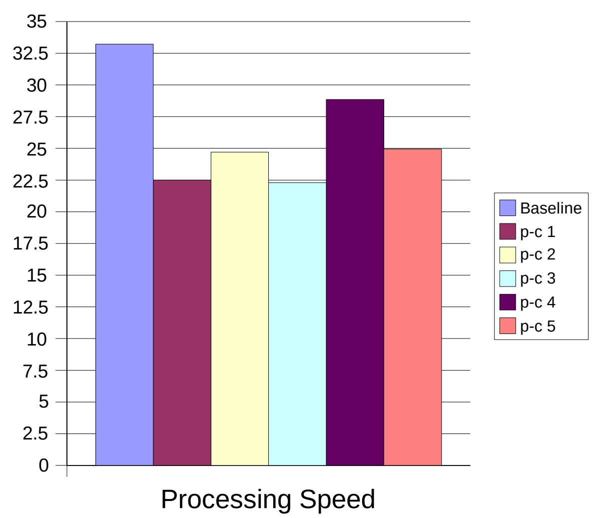


Fig. 2.3. Scores for the Processing Speed Composite at baseline and at the five post-concussion tests (p-c 1 to p-c 5)

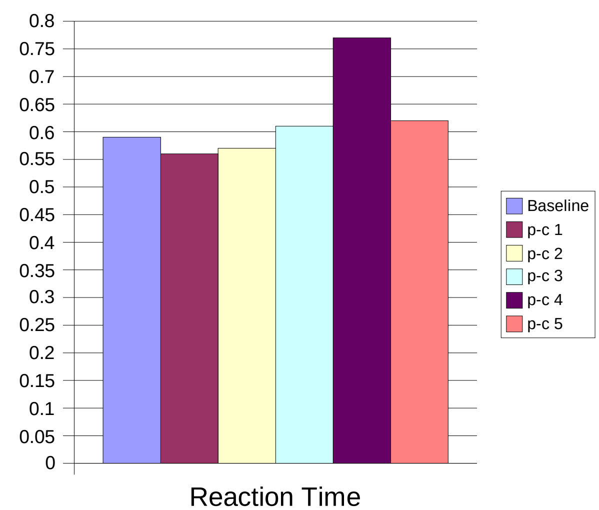


Fig. 2.4. Scores for the Reaction Time Composite at baseline and at the five post-concussion tests (p-c 1 to p-c 5)

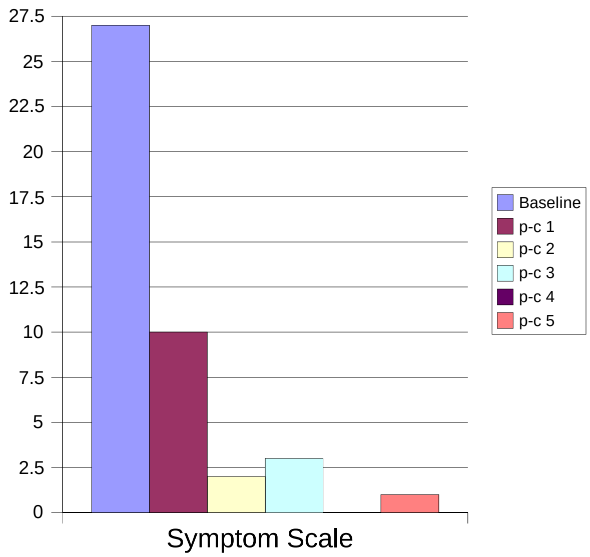


Fig. 2.5. Scores for the Symptom Scale score at baseline and at the five post-concussion tests (p-c 1 to p-c 5)

Analysis of Test Results

Baseline test 12/03/04. Overall, S's baseline scores fell in the low average (upper limit) to average range. Specifically, using both the US and SA normative ranges, S's scores for Verbal Memory and Visual Memory fell comfortably in the average range (see Table 10). The Processing Speed and Reaction Time scores fell marginally below the average range using the US normative ranges, but fell in the lower limits of the average range using the SA normative ranges (see Table 3, p.28). S's lower Processing Speed score relative to his Memory scores, could be explained in part by Calhon & Temple's (2004) observation, namely that a lower processing speed ability, in relation to other cognitive modalities, has been observed amongst children with neuropsychiatric disorders including ADHD. With reference to S's clinical history it was noted that he had been diagnosed with both Tourettes's Syndrome and ADHD andtherefore it seems possible that these conditions could have resulted in the relatively lower score for this composite. While the overall range of low average to average results for baseline levels is not unexpected, considering S's scholastic record and clinical history, as he had been observed to be talking at times during the baseline testing procedure, these scores could be slightly lower than his optimal performance. The Symptom Scale score fell in the very high range using US normative ranges and in the unusual range using the SA normative ranges. Physical, cognitive and emotional symptoms were rated, with particular emphasis (all rated a '3') on three physical symptoms -fatigue, trouble falling asleep and visual problems and on one cognitive symptom - difficulty remembering (see Table 11).

The *first post-concussion test (17/05/04; two days after injury).* Improvement on three of the ImPACT cognitive scores relative to baseline was recorded, with decline noted only on Processing Speed. Specifically, Verbal Memory and Reaction Time showed a slight improvement on the baseline score and both composites fell in the average range using the US and SA normative ranges. An improvement from baseline level (average range) was also noted for the Visual Memory score which now fell in the high average range using both normative ranges. However, Processing Speed showed significant decline relative to baseline, using both RCIs and declined from the low average range to the impaired range using US normative ranges and from the average to the borderline range (lower limits) using the SA normative ranges. Although it is more common to find a decline across the cognitive composites following a concussive injury, decline on only one cognitive composite does not preclude the presence of an injury, as the symptoms arising from concussive injuries are extremely variable (Iverson, Lovell et al., 2003). In addition, the processing speed function has been found to be highly sensitive to concussive injuries (Shuttleworth-Edwards et al., 2004). For the Symptom Scale, significant change in the direction of resolution of symptoms from baseline was observed. The score had improved from the very high range at baseline to the unusual range using the US normative ranges and from the unusual to the normal range using the SA normative ranges. Only physical and cognitive symptoms were rated, all of which were graded '1', with the exception of the physical symptom - sleeping more than usual which was rated a '4'. The improved Symptom Scale at the first follow-up post-injury, is unusual. This could be due to under-reporting or a rapid resolution of post-concussion symptoms.

Second post-concussion test (28/05/04, 13 days after injury). This test was postponed for four days as S had contracted flu and sinusitis. Since the previous time of testing, S's scores were largely unchanged: the Verbal Memory composite had again increased slightly on the baseline score and fell in the average range (upper limits) using both sets of normative ranges. Although the Visual Memory and Reaction Time scores had decreased slightly since the last test, these scores were still higher than baseline levels. The Visual Memory composite now dropped from the high average to the average range using both normative ranges, while the Reaction Time composite continued in the average range using both normative ranges. With an improvement of only two points since the last time of testing, the Processing Speed composite still showed significant decline over the baseline score using both RCIs and remained in the impaired range using US normative ranges and in the borderline range using the SA normative ranges. The persistence of the impaired score for Processing Speed could indicate a lingering cognitive deficit resulting from the injury, and/or to the presence of other debilitating factors, possibly S's ongoing flu and sinus problems. The Symptom Score had dropped even further and again showed significant change in the direction of resolution using both RCIs. The score fell from the unusual range to the normal range (lower limits) using the US normative ranges and from the normal to the low-normal range using SA normative ranges. It seemed strange that S was not reporting more symptoms considering his flu symptoms and extensive sinus problems which increases the possibility that S was under-reporting on his Symptom Scale.

Third post-concussion test (04/06/04; twenty days after injury). All the composite scores had declined since the previous time of testing: the Verbal Memory composite, for the first time since the injury, showed significant decline using both RCIs, and had declined from previous results in the average range (upper limit) to borderline range (lower limit) using the US normative ranges and impaired range using the SA normative ranges. The Visual Memory score had declined slightly since the previous test, but continued above baseline level and still fell in the average range using the US and SA normative ranges. The Processing Speed score continued to show a significant decline using the RCIs and fell once again in the impaired range (US normative ranges) and borderline (lower limit) range (SA normative ranges), having declined by 2.4 points. The Reaction Time had deteriorated slightly on the baseline level for the first time since follow-up testing began. In terms of the US normative ranges this decline was reflected in a change of ranking from average (at the last test) to low average range. Using the SA normative ranges a slight drop from average to the lower limits of the average range was noted. Not much change was noted on the Symptom Scale which only increased by one point, again showing a significant improvement on the baseline score and continuing in the normal range using the US normatives ranges and in the low-normal range using SA normative ranges. Only two physical symptoms were rated: headache and visual problems. Following the deterioration in cognitive scores a medical check-up was recommended to rule out the possibility that the uncharacteristic worsening of the cognitive scores at this stage, might be due to neuropathological complications as a result of the concussive injury. A CT scan was subsequently conducted (see clinical observations), with a negative result, but evidence of extensive sinus problems was reported.

Fourth post-concussion test (23/06/04, five weeks and four days after injury) The results showed a variety of improvements and declines across the composites. The improved score for the Verbal Memory composite could be the result of a practice effect as the baseline test was mistakenly chosen by the athlete in place of the next consecutive post-concussion test (which could affect the Verbal Memory components, the other cognitive components being randomised). This score fell in the high average range using both normative ranges. The Visual Memory score was largely unchanged since the previous time of testing, reflected the baseline score and continued in the average range using both normative ranges. The Processing Speed score had improved since the previous time of testing, but still showed significant decline using the US RCIs and bordered on the level of significant decline using the SA RCIs. Using the US normative ranges, the Processing Speed score improved from the impaired range to the borderline range and from the lower limits to the upper limits of the borderline range using the SA normative ranges. The Reaction Time score showed further deterioration since the previous time of testing, now showing significant decline on baseline scores using both RCIs, for the first time since follow-up testing started. The score worsened from the low average range to the impaired range using the US normative ranges, and from the average range to the impaired range using the SA normative ranges. It does not seem likely that the new deterioration on the Reaction Time composite can be attributed to the concussive injury at this stage of the testing procedure, and is more likely due to lowered motivation or sinus difficulties. The Symptom score was significantly lower than baseline scores using the RCIs, and fell in the low-normal range using both the normative ranges.

Fifth post-concussion test (post-season) (09/13/04) A general return to baseline scores or better was noted, with the exception of the Processing Speed composite. Since the previous time of testing, the Verbal Memory score continued in the high average range using both norms, while the Visual Memory score continued in the average range using both sets of normative ranges. The high scores reported for Verbal Memory could be due in part to practice effects as S unfortunately had repeated the baseline test once again. The Processing Speed score had declined since the previous test, reaching significant levels of decline relative to baseline, falling from the borderline to the impaired range using the US normative ranges, but continuing in the borderline range using the SA normative ranges. The persistent decline could be explained by attention fluctuations and/or ongoing sinusitis complications or lingering cognitive deficit arising from the injury. S also disclosed he had recently begun a course of ritalin medication which could possibly have impacted on his scores. The Reaction Speed score had improved and returned to near baseline levels, no longer showing significant decline. This improvement on the Reaction Time score was reflected using the normative ranges with a change from the impaired range to the low average range. The Symptom Scale score was similar to the previous time of testing, and continued to show a significantly improved score relative to baseline and fell in the normal range using the US normative ranges and in the low-normal range using SA normative ranges. In sum, over the course of all the follow-up test assessments, all the composite scores had shown a marked improvement on baseline scores on at least one occasion with the exception of the Processing Speed composite.

With reference to fig. 2.1 a gradual increase in scores relative to baseline can be observed for the Verbal Memory composite over the test occasions, with the exception of the decline at the third follow-up test. However, these Verbal Memory scores need to be interpreted with care, as it seemed likely, that due to his unco-operative behaviour during the baseline testing procedure, S's baseline score for this cognitive composite, (as well as for all the other cognitive composites), could be lowered. In addition, the last two post-concussion results for Verbal Memory could well be inflated due to practice effects gained from repeating the baseline test. It would appear then, that the post-concussion scores for the Verbal memory composite have remained close to baseline level throughout the test occasions. The Visual Memory composite (see fig. 2.2) showed a subtle improvement on baseline level at the first post-concussion test, followed by a gradual, minor decline back to baseline level, with a final increase above baseline levels at the final test. As it is likely that the baseline score of this cognitive composite is also slightly lowered, it appears possible that the scores for this cognitive composite have, like the Verbal Memory scores, largely remained at baseline level across the test occasions. The fluctuations on the Processing Speed composite (see fig. 2.3) are clearly displayed, with post-concussion scores never returning to baseline level on any test occasion. If it is assumed that the baseline score is slightly lowered, the persistent decline on this composite becomes more substantial. The Reaction Time scores (see fig. 2.4) show an inverted pattern - namely a marginal initial increase on baseline levels, followed by a gradual decline back to baseline levels, (apart from the large decline at the fourth follow-up). None of the above cognitive composites showed the characteristic initial decline after injury, followed by gradual improvement over baseline levels that can generally expected from a mild concussive injury (Lovell, Collins et al., 2004).

The Processing Speed composite in particular has been known to exhibit a practice effect on the post-concussion tests in some athletes (Iverson et al., 2003), but is the one composite in this set of scores that did not attain baseline levels. The persistent decline on S's Processing Speed composite could be explained in terms of i) recent research findings which link a vulnerability on the Processing Speed cognitive function with ADHD (Calhoun & Temple, 2004), and ii) research which has shown that the Processing Speed function is particularly sensitive to concussive injury (Echemendia et al., 2001; Shuttleworth-Edwards et al., 2004). Further in terms of according to the Brain Reserve Capacity (BRC) theory (Satz, 1993), a neuropsychiatric disorder (such as ADHD and Tourette's Syndrome in S's case), increases the risk of functional impairment following a injury by having the effect of lowering the protective threshold factor (Satz, 1993). In the light of S's baseline score for Processing Speed, it apears that the low post-injury scores recorded for this composite cannot be attributed to a pre-morbid weakness alone or to the sensitivity of this function to the concussive injury alone, but rather as a consequence of subtle functional impairments resulting from the cumulative effects of the concussive injuries on a margin of brain reserve, already limited by a pre-existing neurological disorder, is becoming evident. It seems probable that S's difficulties with extensive sinusitis may also have contributed to the lowered performance on these scores.

Overall, similar results were found between the US and SA RCIs and scores fell in similar ranges using the two sets of normative ranges, which in turn reflected the changes in baseline scores. A slight discrepancy in classifying scores using the normative ranges was found for the Symptom Scale score, with scores generally falling in a range higher than that when using the SA normative ranges. Using the SA normative ranges, made S's apparent tendency to under-report symptoms more obvious, than when using the US normative ranges.

3.4 CASE 3

Concussion history

Present concussion: 31/07/2004 M appears to have sustained a concussion while playing in a rugby match. According to his uncle who had observed the occurence, the injury happened about five minutes into the game. There was an enormous impact due to the fact that M was dragging two rugby players with him before falling onto the ground. M seems to have lost consciousness briefly, for a few seconds. He was conscious by the time the coach arrived, about three minutes later. Medical personnel attended to him for about 10 minutes, applying ice packs and then assisting him to the side of the field where he remained for the rest of the match. According to Mr B, M was clearly not himself, appearing dazed and stunned with a vacant expression and complained of a sore jaw. He answered his uncle in monosyllables, although this was not too unusual as M is apparently a quiet and reserved person. M was unable to remember the rest of the first half of the game after the injury, but could remember events prior to the injury, namely, that two tries had been scored in the opening minutes. M could not recall how the concussion happened, but reported that he fell to the ground after being tackled by two rugby players. Reported retrograde amnesia was assessed as > 15 minutes, anterograde amnesia between 1- 5 minutes and confusion and disorientation for >30 minutes. As the injury occurred at an "away" match and M is a day scholar, he was not attended to by the school sanatorium and doctor. It is uncertain, whether this concussion was confirmed by a medical doctor, but the reported symptoms strongly suggest that a concussion was sustained.

Prior concussion/s: 1996 One prior concussion was reported which included LOC, confusion and amnesia. A total of three rugby games were missed as a result.

Other relevant history

Medical: M had been treated for headaches by a doctor.

Psychiatric: None reported.

Educational: M was completing a post-matric year at the time of testing and achieved a high B aggregate. His academic results mid-year were English (HG) - C, Afrikaans (HG) - B, Maths (HG) - B, Computer Science (HG) - C, Physical Science (HG) - B, Accounting (HG) - B. A premorbid estimate of functioning based on these results place M in the average (upper limits) to high average range.

Results: Baseline (12/03/04), three follow-up tests (02/08/04; 06/08/04, 13/09/04).

Clinical Observations

First post-concussion test 02/08/04: M reported an ongoing headache since the day of the injury, and indicated the top and back of his head on the right hand side. He had felt dizzy at times on the Saturday night when he turned over in bed, but had not felt dizzy since then. M reported that he felt jumpy when he heard a loud noise, was feeling tired, sluggish and foggy. He had slept longer than normal on Saturday night, about 12-13 hours.

Third post-concussion test 13/09/04: It was observed that he and a fellow athlete, who was completing the test in the same room, were talking at times. It is possible that lowered motivation may have impacted negatively on his scores.

ImPACT Test Results: These appear in Tables 12 and13 and fig.3.1-3.5 below.

Table 12. Summary of the ImPACT test results for the baseline test and three post-concussion tests in comparison to the US and SA Normative Data for high school boys ages 16 - 18 years in

the average range

ImPACT scores	***Baseline***	***02/08/04 (p-c 1)***	***06/08/04 (p-c 2)***	***13/09/04 (p-c 3)***	***US Norms average range***	***SA Norms average range***
Verbal Memory	87	84	95	96*	80 - 92	81 - 93
Visual Memory	76	74	93	81	71 - 88	71 - 86
Processing Speed	34.5	33.9	31.7	32.2	33.7 - 42.5	33 - 42.6
Reaction Time	0.50	0.53	0.49	0.53	0.58 - 0.5	0.61 - 0.55
Symptom Scale	2	**24***	0	0	1 - 6	9 - 18

* Denotes significantly poorer performance relative to baseline scores using the US RCIs.
Bold type denotes significantly poorer performance relative to baseline scores using the SA RCIs.

Table 13. Self-reported postconcussion symptoms from the ImPACT Symptom Scale in three categories, at baseline and at the three post-concussion tests

Date of testing	***Total score***	***Physical Symptoms***	***Cognitive Symptoms***	***Emotional Symptoms***
Baseline (12/03/04)	2		difficulty remembering (2)	
First post-concussion test (02/08/04)	24	headache (5); fatigue (4); sleeping more than usual (3); drowsiness (2); sensitivity to noise (2)	feeling slowed down (3); feeling mentally foggy (2); difficulty concentrating (3)	
Second post-concussion test (06/08/04)	0			
Third post-concussion test (13/09/04)	0			

In graphical representation, ImPACT results are shown below for the cognitive composites Verbal Memory, Visual Memory, Processing Speed, Reaction Time and for the Symptom

Scale scores at the baseline test and at the three post-concussion tests.

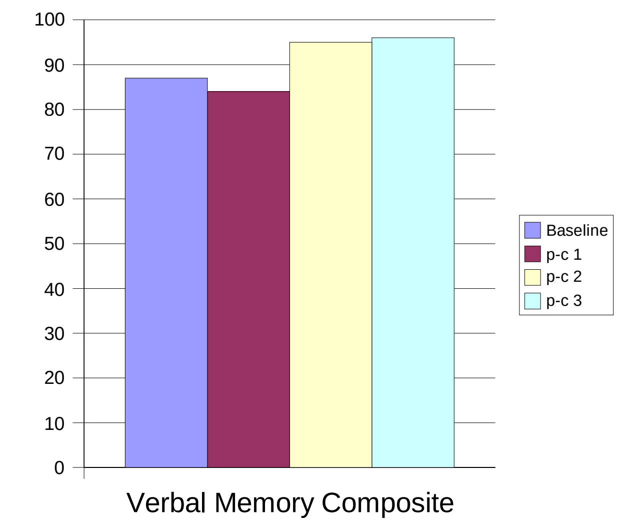


Fig. 3.1 Scores for the Verbal Memory Composite at baseline and at the three post-concussion tests (p-c 1 to 3)

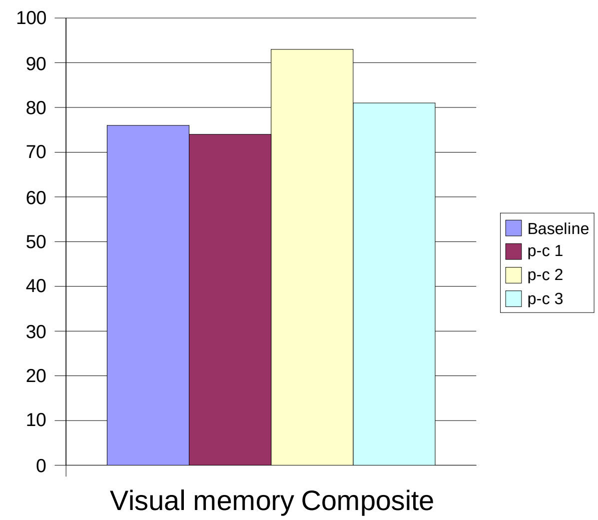


Fig. 3.2 Scores for the Visual Memory Composite at baseline and at the three post-concussion tests (p-c 1 to 3)

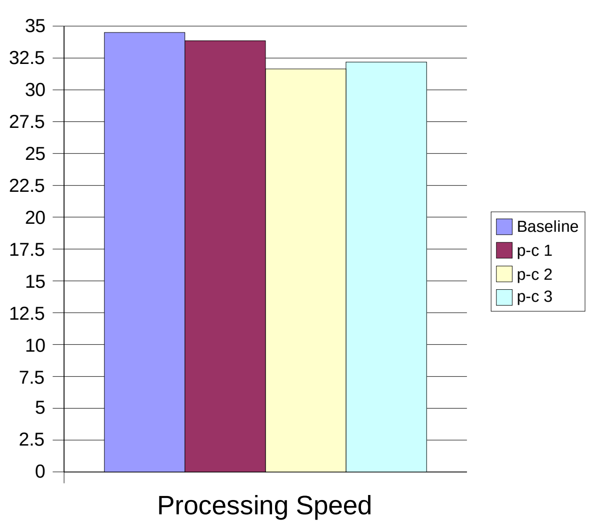


Fig. 3.2 Scores for the Processing Speed Composite at baseline and at the three post-concussion tests (p-c 1 to 3)

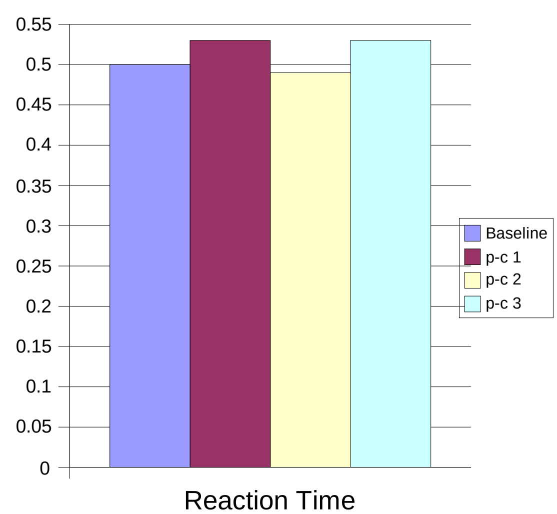


Fig. 3.3 Scores for the Reaction Time Composite at baseline and at the three post-concussion tests (p-c 1 to 3)

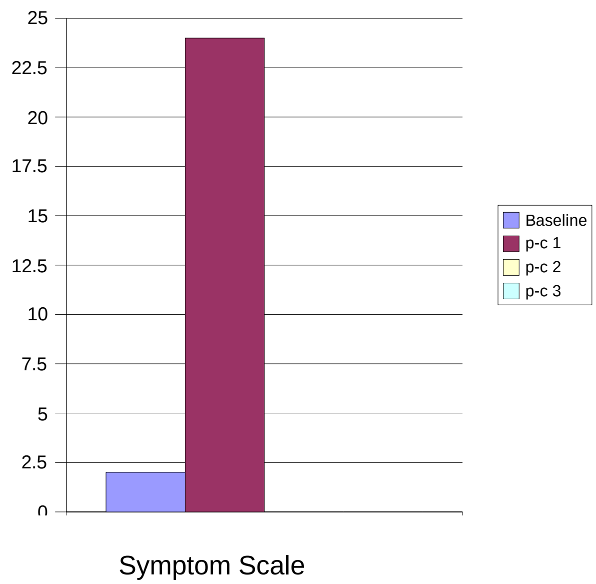


Fig. 3.5 Scores for the Symptom Scale at baseline and at the three post-concussion tests (p-c 1 to 3)

Analysis of Test Results

Baseline assessment (12/03/04) M's results fell in the average range for Verbal Memory and Visual Memory and in the lower limit of the average range for Processing Speed using both US and SA normative ranges (see Table 12). M's reaction Time scores fell in the upper limits of the average range using US normative ranges and in the superior range using SA normative ranges (see Table 3, p.28). The Symptom Scale score fell in the lower limits of the normal range using the US normative ranges and in the lower limits of the low-normal range using the SA normative ranges. The results for the baseline test were slightly lower than expected in view of M's academic results. It is possible that the conditions of the baseline test (a large group of 15 participants) could have distracted him and resulted in a less than optimum performance.

First post-concussion test (02/08/04, 2 days after injury). None of the cognitive composite scores showed a significant decline, but there was a marginal lowering across all cognitive composite scores. Using the US and SA normative ranges, M's results for Verbal Memory and Visual Memory still fell in the average range and in the lower limit of the average range for Processing Speed. The Reaction Time score showed a subtle decline using the normative ranges, shifting from the upper to the lower limits of the average range using the US normative ranges and from the superior to high average range using SA normative ranges. The Symptom Scale score however, showed a significant increase from baseline level using both RCIs. Using the US normative ranges, M's Symptom Scale score deteriorated from the normal to the very high range, but from the low-normal to the unusual range using the SA normative ranges. A number of physical and cognitive symptoms were rated and given relatively high scores (see Table 13): physical symptoms included headache (5), fatigue (4) and sleeping more than usual (3), while cognitive symptoms rated included feeling slowed down (3), and difficulty concentrating (3) (see Table 13). The subtle overall decline on all cognitive scores and the significant increase in symptom reporting can be observed on the bar graphs (see figs 16-19 below). These results indicate the prescence of both cognitive and symptomatic sequelae that can be attributed to the concussive injury. It seems possible that the mild, rather than significant, decline observed on the cognitive composites can be attributed both to the nature of the injury, as well as that fact that M did not a history of two or more prior concussions or a history of psychiatric difficulties. Consequently, in terms of the Brain Reserve Capacity Theory, M's cognitive functioning was less vulnerable to the effects of brain injury, having a relatively high brain reserve capacity.

Second post-concussion test (06/08/04, six days after injury). General improvement was shown on most composites and symptoms had resolved completely. The Verbal Memory score exceeded average baseline levels and now fell in the high average range using the US and SA normative ranges. The Visual Memory score had also improved and showed a significant change from the baseline level using both RCIs. Using both sets of normative ranges, the Visual Memory score improved from the average to high average range (upper limit). Processing Speed had declined slightly since the last time of testing, and now fell in the low average range using both normative ranges. The Reaction Time score had improved on the baseline score and now fell from the average range to the lower limits of the high average using the US normative ranges and in the superior range using the SA normative ranges. No symptoms were reported, showing a substantial improvement since the last time of testing and a slight improvement on baseline levels using the RCI'. M's Symptom Scale score fell in the low-normal range using both sets of normative ranges. In sum, with the exception of the subtle decline on the Processing Speed score M showed a good recovery on all scores. In most instances the scores recovered to a level higher than the baseline levels and more in keeping with his expected potential based on his scholastic record. This supports the hypothesis that a less than optimal performance was recorded at baseline due to group testing conditions. It is necessary to discern however, whether the lower Processing Speed score is indicative of a lingering deficit arising from the injury or due to some other factor: In cases of lingering cognitive decline the worst performance is expected at the first follow-up, not the second, as here. A delayed onset of complications was also unlikely, as this is more commonly found within the first 48 hours and is normally accompanied by symptoms (which were absent at the second follow-up). It was also unlikely that M was under-reporting symptoms as the rugby season was now over. With reference to M's baseline score, it can be seen that Processing Speed was his weakest score relative to the other composites (see Table 12), falling in the lower limits of the average range. This could be due to a natural range of ability and, in sum, seems a more likely explanation for the marginally lowered score, than a lingering deficit arising from the injury.

Third post-concussion test (Post-season) (13/09/04). A mix of improved and slightly declined scores were recorded. The Verbal Memory score continued to show significant improvement on the baseline score and fell in the high average range using the US and SA normative ranges. The Visual Memory score had declined since the previous time of testing, no longer showing significant improvement, but still evidenced an improvement on the baseline score. The score showed a decline from the high average (upper limit) to the average range using both normative ranges. The Processing Speed result showed a slight improvement since the last time of testing, but had not yet returned to baseline levels, and remained in the low average range using the US and SA normative ranges. Reaction Speed showed a slight decline compared to the baseline level and previous time of testing, falling from the high average (lower limit) to the average range using the US normative ranges and from the superior to the high average range using the SA normative ranges. As at the previous time of testing, no symptoms were reported which again showed a slight improvement relative to the baseline score. The Symptom Scale score continued in the low-normal range using both sets of normative ranges. Overall, recovery could be said to be complete, despite the subtle decline on the Reaction Time and Processing Speed scores (relative to baseline levels).

The lack of symptom presentation accompanying the slight decline in scores (with no obvious motive to under-report symptoms), and the fact that better results for these composites had been recorded at previous follow-up occasions, suggest that the subtle declines at the third post-concussion test can be attributed to lowered motivation, or distractibility as M was observed to be talking during the post-season test. While some sign of practice effect might have been expected for the Processing Speed composite by the third post-concussion test, the absence of a prior history of multiple concussions or neuropsychatric disorders makes it unlikely that the marginal fluctuation observed on his scores at the final follow-up can be attributed to lingering cognitive decline.

The two RCIs indicated similar levels of decline throughout, but using the normative ranges marginal differences between the classification ranges were obtained in some instances for the Reaction Time and the Symptom Scale scores. Generally it was observed that using the US normative ranges, the Reaction Time score fell in a range lower than when using the SA normative ranges. These differences would not have affected management results based purely on analyses using normative ranges, as scores fell in average and above average range using both sets of classification ranges. Without prior knowledge of the baseline scores it would have been impossible to chart the subtle decline on the cognitive composites at the first follow-up. The 'very high' range for the first Symptom Scale score using the US normative ranges seemed a better reflection of the significant change in M's score relative to his low baseline score, than when using the SA normative range where the score fell in the unusual range.

Chapter 4: DISCUSSION

Although many concussive injuries resolve rapidly (within one to two weeks) and without any residual problems (Macciochi et al., 1996; Echemendia et al., 2001), a significant number of concussed athletes, estimated at about 10-15%, continue to be affected by postconcussive symptoms up to 6 weeks or even to 6 months in some cases (McAllister & Arciniegas, 2002). Research studies have also shown that an athlete who sustains a number of concussive injuries over time may be at risk for permanent cognitive decline (Lovell & Collins, 1998). In addition, concussive injuries have been linked to Second Impact Syndrome, occuring when the brain - made vulnerable by a previous injury - sustains a second blow, which can result in severe brain injury or death in some cases (Fischer & Vaca, 2004). In a response to the critical dangers inherent in the seemingly mild concussive injury, attempts have been made in the past to manage these injuries through a system of severity grading (LeClerc et al., 2001). The varied presentation of the concussion injury, along with a lack of supporting empirical research studies have been a major obstacles in establishing a uniform grading system (Lovell et al., 2004). In the past five years however, important developments have been made in terms of research and in attempts to clarify and gain consensus for management protocols (as in the International Concussion Conferences held in 2001 and 2004) (Aubrey, 2001; McCrory, 2005 respectively). This has resulted in the introduction and development of new management approaches to concussive injuries as well as in more sophisticated assessment instruments.

The investigation undertaken in this study was in response to the recent development of computerised neuropsychological assessment methods to monitor and manage concussions. Computerised neuropsychological testing, now recognised as a key assessment tool in managing the concussive injury, is able to accomodate the diversity of concussion presentations as it provides a method of assessment and management which is based on *individual* scores, namely pre-season baseline scores, which provides a comparative measure for subsequent post-injury testing (Guskiewicz et al., 2004). In addition, the development of computerised neuropsychological testing programmes has made neuropsychological testing an option for school athletes for the first time, as the traditional pencil and paper methods were too costly and time consuming (Collie et al., 2001; Lovell & Collins, 2002). This has been an important advancement for concussion management at the school level, as research has shown that adolescent athletes as a group are most at risk for concussive injuries, particularly injuries of a more severe nature such as Second Impact Syndrome (Lovell et al., 2003). High school athletes were the specific focus of the present research as there have been very few research studies undertaken on this population, despite their greater vulnerability to injury (Guskiewicz et al., 2004). ImPACT was the specific computerised neuropsychological test chosen for this study, due to the impressive number of validity and reliability studies published to date.

From the cases investigated, a number of key issues emerged which will be discussed below

1) The diversity of concussive injury presentations illustrated by the cases referred to the researcher. 2) The utility of the neuropsychological assessment in the follow-up process. 3) A comparison of the interpretative methods currently avaliable for analysing ImPACT test scores (i.e. the use of baseline data combined with Reliable Change Indices (RCI's) versus the use of normative ranges), including an assessment of the most suited method of analysis for the school setting. 4) The influence of co-morbidity factors on the post-concussion scores. 5) Management recommendations for the athletes followed-up in the study.

4.1 The diversity of concussive injury presentations

The critical problem associated with the varied presentations of concussion is that certain concussions may pass undetected by coaches, while others may be regarded as insignificant and therefore not warrant further assessment. Consequently, the potential arises for an athlete to incur a more severe injury if he or she, while still vulnerable from a previous injury, sustains a second concussion. The diversity of concussive injuries was clearly demonstrated by the four quite different presentations of concussions which were brought to the attention of the researcher. The first injury sustained by N, in Case 1, included a brief loss of consciousness (LOC), amnesia, as well as a substantial number of physical, cognitive and emotional symptoms being reported; while N's second concussion (which was not observed by the coach) resulted in momentary dizziness with few symptoms reported. S, in Case 2, presented with no LOC, no amnesia, and little symptomology, while M in Case 3 presented with brief LOC, amnesia, and a fairly high number of physical and cognitive symptoms. Confusion and uncertainty was evident in each case regarding both the diagnosis of the injuries and in their appropriate management: The school coaches were suspicious of Case 1's injuries (due to a history of behavioural problems) despite the doctor's diagnosis. In Case 2, it appeared that the school doctor was not completely certain whether S's injury was, in fact, a concussion, but decided to treat it as such. Some doubt was also raised by one of the coaches as to whether Case 3 had sustained a concussion. The discussion below will explore how the implementation of the computerised neuropsychological test was able to bring some measure of clarity and understanding to the nature of the concussive injuries sustained by these athletes and to their appropriate management.

4.2 Utility of the neuropsychological assessment in the follow-up process

The diagnosis of the concussive injury is typically made by the medical practitioner attending to the injured athlete. However, assessment measures on computerised neuropsychological tests (such as ImPACT), can contribute to the confirmation of the injury, by giving information regarding subtle cognitive decline, a common sign that a concussive injury has been sustained (Macciochi et al., 1996). Subtle (or more substantial) cognitive decline is not easily achieved by other assessment methods such as brief sideline assessments (Collins et al., 1999). It has been common practice for coaches to rely on athletes' self-report to determine the severity of the injury and when the athlete should return to play (Guskiewicz et al., 2004). Self-report of symptoms, however, is notoriously unreliable and under-reported amongst athletes, particularly high school athletes, due to a naivety regarding the nature of the injury, a desire to continue playing or an unwillingness to let their team players down (Field et al., 2003). The significant decline on N's (Case 1's) cognitive results across all cognitive composites for both concussions sustained, was convincing evidence of the presence of a concussive injury. These results countered doubts from the coaches as to whether he was concussed, in both instances, as well as N's subsequent attempts to deny that a second concussion had taken place. Iverson, Lovell et al. (2003) have shown that athletes sustaining concussions were 47 times more likely to present with two or more declines across the five ImPACT scores than nonconcussed participants, and that 44-54% of athletes sustaining concussions show statistically reliable declines over the four cognitive composites and symptom scale score. In contrast to Case 1, Case 2's first follow-up results recorded only one significant decline amongst the test results, namely that of Processing Speed - a function known to be particularly sensitive to diffuse brain damage (Echemendia et al., 2001). Authors Iverson, Lovell et al., (2003), however, also make the point, that "some athletes experience immediate pronounced problems whereas others experience very mild problems that resolve quickly. All athletes are not expected to show cognitive problems on neuropsychological testing, even in the first couple of days post-injury" (p. 456).

Thus significant general cognitive decline can be a clear sign that a concussion has occurred, but its absence does not rule out the possibility that a concussion has occurred. This was further evident from the results for M, in Case 3, where only very subtle decline across all four cognitive composites were recorded at the first follow-up, with significant change only observed on the Symptom Scale score. Cases 2 and 3 also illustrated the important emphasis given by most developers of computerised neuropsychological tests, namely that the neuropsychological test is only one of the tools used to make management decisions and needs to be incorporated together with all the athlete's other clinical information and assessment results for the final management decisions (Lovell & Collins, 2002).

The critical information that can arise from the neuropsychological test as discussed above, casts some uncertainty on the new recommendations suggested by the Prague Statement (2004), which reserves the use of neuropsychological testing for the category of 'complex' concussions alone and not for 'simple' concussions, the alternate proposed category. 'Complex' concussions are defined as those where athletes suffer persisting sequelae, prolonged LOC, or prolonged cognitive impairment, multiple concussions or where subsequent concussions with less force result in increasing impairment. 'Simple' concussions on the other hand are those concussions which will remit without complications in 7- 10 days. In the three cases followed-up, however, none, at the outset, met the requirements for a 'complex' concussion assessment. While M, in Case 3, appears to fit the definition of a 'simple' concussion with symptoms resolving within a week, the concussions sustained by N, in Case 1 and S in Case 2, in retrospect indicated more complex injuries: 9 days after the first reported concussion for Case 1, incomplete recovery was evident from the significant declines and scores falling below the expected normative range for the cognitive scores, while Case 2 was also still showing significant decline on the Processing Speed composite at day 12. These findings illustrate potential problems with the new Prague recommendations for classifying concussions, as only the use of neuropsychological testing was able to differentiate between simple and complex concussions in these cases. Recommending that neuropsychological testing be reserved for complex concussions alone, seems therefore problematic and potentially hazardous.

Neuropsychological testing also plays a crucial role in the monitoring of the concussive injury and in assessing when recovery is complete. These aspects will be discussed further in the section below.

4.3 Methods of interpretation: baseline scores combined with RCI's versus normative data ranges

Recent concussion guidelines published, for example the National Athletic Trainers Association Concussion Guidelines (NATA), 2004 as well as the Vienna and Prague Statements (Aubrey et al. 2001 and McCrory et al., 2005 respectively), recommend that baseline testing be conducted where athletes are at risk for concussive injuries, as individual baseline scores can provide a more accurate measure against which post-injury scores can be compared (using RCIs) than that provided by normative data for the expected range (based on a scholastic history). However, despite the advancements that computerised neuropsychological testing has created in enabling neuropsychological testing to be an option in the school setting, integrating the necessary baseline testing procedures into the school programme is not as straightforward as it may seem. Much time and planning and possibly training of administrators may be required (about three months of planning, according to Guskiewicz et al., 2004), particularly where the numbers of children involved with contact sport run into the hundreds in a single school. In addition, it has been recommended that high school athletes be baselined annually due to their rapid cognitive maturation (McCrory et al., 2004). Therefore, it appeared useful to investigate whether baseline testing was warranted in the school context or whether normative data alone could provide sufficient management guidance on post-injury test scores on the computerised neuropsychological test (i.e. ImPACT in this study). Two sets of RCIs were utilised in the present study to calculate levels of significant decline on post-injury scores i.e. a US developed set (Iverson, Lovell et al., 2003) and a SA version (Shuttleworth-Edwards et al., 2005). In addition post-injury test results were compared against expected normative ranges. Two sets of normative ranges were used in the present study: the US normative ranges for high school boys in the age range 16-18 years developed by Iverson et al. (2002) and the recently devised SA normative ranges for a comparative group and age range (Shuttleworth-Edwards et al., 2005).

For a comparison of the US and SA RCIs and US and SA normative ranges for cognitive and symptom scores see Tables 3 - 5 (p.28 - 29). It can be observed that the SA RCI intervals are slightly wider than the US RCI's. The differences between the RCIs could be accounted for by the different test-retest intervals used i.e. m = 5.8 days for the US sample and m = 5-6 months for the SA sample. An additional exclusion was applied to the SA sample, i.e. those athletes with a history of more than one concussion, which could also have affected results. While in most cases the US and SA normative classification ranges are very similar, the US normative ranges for the Reaction Time composite are lower (i.e. faster) than the SA normative ranges. The US and SA normative ranges for the Symptom Scale scores also differed, i.e. wide discrepancies in scores between the normative ranges were observed with SA classification ranges being higher and more varied in scores than the US normative ranges. The discrepancies between normative ranges for the Symptom Scale scores could be the result of cultural differences. In the process of the present study, results in relation to US RCIs and US normative ranges were also compared to the new SA RCIs and SA normative ranges to ascertain whether either set of databases yielded more relevent guidelines for SA high school athletes.

Despite the slight differences between the two sets of RCIs, the overall indications of significant decline relative to baseline scores on post-concussion testing was virtually the same in every instance. Using the US and SA normative ranges likewise indicated the significant declines with scores falling in the impaired and borderline ranges. However, slight differences were observed between analyses using the two normative ranges for the Reaction Time results, and more noticeable differences were found for the Symptom Scale. That is, the scores for Reaction Time fell in different classification ranges using the two normative ranges on two test occasions: At Case 1's second follow-up (first concussion), the Reaction Time scores fell in the borderline range using the US normative ranges and in the low average range using the SA normative ranges. Similarly at Case 1's first follow-up (second concussion) using the US normative ranges, the score fell in the 'borderline' range, compared to the 'low average' using the SA normative ranges. The corresponding results in both instances using baseline scores was that of significant decline or bordering on significant decline, which seems best reflected by the indication of borderline range usng the US normative ranges. However, as the scores in both instances fell below the expected average range, concern regards an incomplete recovery would have been raised using either normative range. Discrepancies amongst classification ranges between the normative ranges for Reaction Time scores were not evident for Cases 2 and 3.

In contrast, more obvious differences in score interpretations between the baseline and RCIs versus normative ranges were found for the Symptom Scale score interpretations. Using the two normative ranges resulted in scores falling in the same ranges in most cases, although slight differences were found in Case 1 (first concussion) and Case 2. These discrepancies were minor, however and would not have resulted in different management results. The baseline scores however, were important in providing a yardstick with which to interpret the post-injury scores, most particularly because of the subjective nature of this self-report scale. In Case 1 (first concussion), a high Symptom Score was recorded at baseline, subsequently allowing for the observation that symptoms had returned to normal at the second post-concussion assessment, where the score, using the normative ranges alone, falls in the 'unusual' range, suggesting ongoing symptomology. N's third follow-up showed a significant drop in the Symptom Scale score, well below baseline, which was however, interpreted as 'normal' using the US normative ranges and 'low-normal' using the SA normative ranges. Possessing a baseline score, therefore allowed for the observation that N was either under-reporting symptoms in that instance, or was slowly becoming more realistic in his self-appraisal of symptoms over the course of the testing procedures. In Case 2, S's low Symptom Scale result at the first post-concussion assessments was significantly lower than his baseline score suggesting the possibility that he was under-reporting symptoms. This observation would not be evident using the normative ranges alone, which recorded a 'normal' result using the SA normative ranges and an 'unusual' result using the US normative ranges. No major differences between the two interpretative methods or between the two normative ranges were found in Case 3's Symptom Scale results.

Overall, then it seems that it may be preferable to utilise SA normative data for the Symptom Scale in preference to the US data. While the normative ranges offer some context in which to interpret the scores, it appeared more important to have baseline scores to assess these subjective post-injury scores. With the Reaction Time normative ranges being slower overall in the SA sample compared to the US sample, it might seem more appropriate to utilise these scores. However, in two instances in Case 1's follow-up tests the US normative data for Reaction Time appeared to be a closer reflection of the decline relative to baseline than was evident in relation to the SA normative ranges, and therefore it may be safer to take cognisance of the more stringent US normative range for this composite.

The relative efficiency of baseline data versus normative ranges in determining recovery from the ImPACT post-concussion test scores: Deciding whether an athlete has recovered sufficiently to return to play is a decision that needs to be made carefully to prevent further injury and be based on strong indications that the athlete has returned to his premorbid level of functioning. At the outset it appears quite evident that baseline scores will give more accurate indications of recovery than a decision based on normative ranges alone. In Case 1, baseline data was important in determining whether N had made a complete recovery at post-season. Although his final results showed a return to baseline levels, due to the observation that he had been unco-operative during baseline testing, and that his baseline scores were lower than expected, as well as the fact that his post-season scores are only just at the recorded baseline level, it appears possible that an overall decline in cognitive functioning may be in evidence. The normative ranges also seemed to corroborate these findings as his scores did not fall in the expected average ranges, i.e. using the US normative ranges three of N's post-season cognitive composite scores fell in the low average range with only one composite falling in the average range, while using SA normative ranges two scores fell in the low average range and two in the low average range - both sets of interpretations therefore suggesting a partial, but not complete recovery.

Baseline data was also crucial in determining whether or not Case 2's Processing Speed results had returned to normal over the test occasions or whether a persistent decline was being recorded for this composite. While some lowering on this modality could be expected due to the presence of ADHD (Calhoun & Temple, 2004), with the baseline score avaliable it could be clearly observed that full recovery had not been regained over the test occasions. Using the US normative ranges, his Processing Speed score fell in the impaired range and in the borderline range using SA normative ranges at the post-season follow-up, which would also have raised concern that recovery was incomplete for this modality. Using the normative ranges alone, S's scores at post-season fell in varied ranges from impaired to high average, which would have raised concern that recovery was not complete for all cognitive composites. In Case 3, the overall subtle decline on the cognitive baseline scores at the first post-concussion test was only discernable with reference to the baseline scores. However, using the normative data, signs of concussion would have been evident on the Symptom Scale with scores falling beyond the normal range.

Baseline scores therefore serve as important indicators of individual abilities and temperaments, such as an athlete's natural range of cognitive strengths and weaknesses or normal tendency to report symptoms. They also contribute to informing an accurate interpretation and assessment of post-concussion scores and in making decisions whether a full recovery has been made. Certain factors such as low motivation, the onset of illness, fatigue or mood swings can result in lower than optimal scores being recorded for the baseline level. To be alert to this possibility requires clinical observations at the time of testing. Subsequently, such observations would need to be incorporated into the interpretation of results. Normative ranges can also play a role in providing indications of invalid baseline data, as scores falling out of the chosen classification range for the athlete (based on scholastic achievement) could then be investigated either by a retest, or by making use of the athlete's concussion, educational, psychiatric and medical history to make sense out of the data. In this way, normative data provide an important context in which to interpret the athletes' test results.

Over the test occasions it was observed that in most instances the normative ranges gave a similar reflection of the significant changes on the cognitive composites relative to baseline scores, with similar indications for management and were also able to give a sense of the level of severity of the injury by virtue of the classification range. As discussed earlier, normative data revealed some limitations in assessing Symptom Scale scores. Symptom Scale scores would need to be interpreted carefully in the light of the athletes relevant history and motivations. Difficulties using normative data alone also arose when assessing for a complete recovery. In sum, the cases provided important indications of the utility of both the baseline score and normative data for the composite scores, each method providing important information for managing the injury. However it was observed that on the Symptom Scale the combination of baseline scores and RCIs were the better indicators of significant change than the normative ranges and for assessing for full recovery.

It seems likely that for those South African schools which do not have the facilities to conduct large-scale baseline testing of all pupils, subsequent follow-up testing after injury using SA normative data would be useful in providing management guidelines. It would require however, that the interpreter of such results undertake a detailed clinical history of the athlete, in order to obtain an accurate as possible estimate of premorbid functioning. It is also probable that groups of South Africans with less computer skills than the group on whom the SA normative ranges are based, may do less well on these tests when using the current normative ranges. In sum, it can be observed that although computerised neuropsychological assessment provides an important tool for assessing concussion injury, the cases also illustrated the need for a global understanding of the athlete's condition and history in order to effectively interpret the neuropsychological results.

4.4 The impact of co-morbidity on test results

The presence of co-morbid psychiatric or neurological disorders, as well as a history of two or more concussions, can result in lowered cognitive test scores and potentially more severe sequelae resulting from a concussive injury (Collins et al., 1999; Shuttleworth-Edwards et al., 2004). This has been supported both in research (Collins et al., 1999) and in theory (such as the Brain Reserve Capacity, see pathophysiology section p. 9)). A contributing factor to N's (Case 1) delayed recovery on his first concussion, could have been his earlier unreported concussion 14 days earlier. The pattern of same-season repeat injury is described in the NATA report (2004), where it states that these types of repeat injuries typically occur 7 – 10 days after the first injury. The report suggests that this may be due to increased neuronal vulnerability or blood flow changes. It seems possible that a lingering vulnerability from the earlier injury may have contributed to the significant declines observed on all composite scores at N's (Case 1's) first follow-up test, and subsequent delayed recovery.

Iverson, Gaetz et al.'s study (2003) on the cumulative effects of concussion in amateur athletes indicated that young athletes with multiple concussions (three or more), might suffer from cumulative effects. They suggest that these athletes are more susceptible to sustaining injuries of greater severity in the future. N's significant cognitive decline on ImPACT after the second reported concussion (26/06/04) appears to support these findings. Despite this second concussion, just being a minor hit - unobserved by even the coach - it produced test results which reflected the results of N's apparently more severe concussion, a few months earlier (i.e on the 27/03/04). Lovell et al. (2004) suggest that athletes sustaining a mild concussion generally surpass baseline scores on recovery, and it was evident that only two of N's of post-season cognitive composite scores were marginally higher than baseline over the test occasions, a further indication that N was still suffering cognitive deficits arising from the injury. In terms of the Brain Reserve Capacity theory it seems possible that the cumulative effect of five concussions may have reduced brain reserve capacity thereby increasing his vulnerability to functional impairment.

Recent research and reviews on sports concussion (Collins et al, 1999; McCrory et al., 2004; Shuttleworth-Edwards et al., 2004), have observed that athletes with neuropsychiatric disorders are more at risk for persistent cognitive deficit following injury. Reasons for this increased vulnerability have been hypothesized using the Brain Reserve Capacity (BRC) theory (formulated by Satz), which suggests that a premorbid vulnerability factor, such as a neurological disorder, lowers the protective threshold factor of the brain, which in turn, increases the risk of functional impairment following an injury. Although not the diagnosis of ADHD was not confirmed for Case 1, if it was the case, this would have been an added vulnerability factor. S's (Case 2's) premorbid history of Tourette's syndrome and ADHD, could also have served as vulnerability factors resulting in a lowered threshold for showing neuropsychological dysfunction, resulting in what appears to be a subtle overall lowering on all cognitive functions, and most particularly on Processing Speed, which never returned to baseline levels across the test occasions. The apparent declines observed at the post-season assessment therefore may be indicative of an insidious cognitive deficit, compounded by S's ongoing sinus complications.

No premorbid history of psychiatric or medical disorder were reported or observed in Case 3. In terms of the BRC theory, M would have had no obvious vulnerability factors, and in addition, his good academic record, suggestive of a high IQ, would have served as a protective factor against impairment caused by injury. This may explain the relatively uncomplicated initial post-concussive decline and subsequent return to baseline level on all test scores for Case 3, in comparison to the multiple co-morbid features in respect of Cases 1 and 2 and consequently more complicated sequelae following their injuries.

4.5 Management recommendations for the athletes followed up in Cases 1-3

N's (Case 1's) ongoing participation in sport after his second concussion, despite the communicated concerns of the researchers, points to an important need for further education regarding the safe management of concussive injuries in the school context. It was evident that there were times during the past rugby season when he was at risk for severe injury by returning to play while still in the process of recovery. In N's case, the apparent prescence of cumulative effects of concussion (arising from at least five concussive injuries during his school career) and now seemingly presenting as a subtle overall cognitive decline, suggests that he may be at risk for more severe injury should he return to contact sport. However, this decision would be best made after a full neuropsychological assessment. Similarly, it seems advisable that Case 2 be assessed in the future to further investigate his low result on the Processing Speed composite. Should a persistent decline be confirmed, it seems advisable that S refrain from further involvement in contact sports, particularly in the light of his co-morbid disorders. The speedy recovery of M in Case 3, suggests that he could safely return to contact sports without the need for further follow-up. None of the insights discussed above, could have been possible without the ImPACT testing using baselines in conjunction with normative ranges and full clinical assessment that includes scholastic history, past and present medical history and test observations.

4.6 Evaluation of the Study

4.6.1 Limitations of the study. Limitations of this study include the small number of concussion cases followed up i.e. four, which lay within a restricted age range. To achieve increased generalisability, more cases would need to be analysed as well as an inclusion of younger and older athletes. In addition, the athletes participating in this study, as well as those included in the compilation of the SA and US normative ranges, all come from similar, privileged backgrounds. Thus the findings in the present study as well as the normative ranges may not be applicable to less privileged groups, or in cases where the test be completed in an athlete's second language. The context of the baseline group testing procedure was not ideal as some of the athletes were slightly disruptive during the time of testing, which may have had the effect of lowering some results. In future studies, a more controlled means of baseline gathering, by either testing in a smaller group, or with the athletes more widely spaced in the testing laboratory may help to prevent distracting behaviour during the testing procedure. Student volunteers or teachers could possibly called upon to help monitor the scholars as they pertain to the individual cases.

4.6.2 Strengths of the study. Utilising the case study method rather than a group analysis allowed for detailed data gathering and clinical observations which would have not have been possible in a purely quantitative analysis. The case study approach allowed for a more thorough analysis of results, by placing them within the context of historical details and on-going clinical test observations of the athletes. This method also allowed for the critical evaluation of generalised recommendations such as the recent Prague Statement.

4.7 Conclusion

In conclusion, the implementation of the ImPACT computerised neuropsychological testing in the cases followed up, allowed for the clarification and confirmation of the likely prescence of a concussion in each case by detecting both subtle and significant declines on the neuropsychological test composites, relative to the athletes' baseline scores and expected normative ranges. The process of individualised post-injury serial testing allowed for the monitoring of the athletes' recovery path as well as the identification of persistent of cognitive deficits in certain cases. As a result, crucial information for management recommendations became avaliable, both for discerning complete recovery or to bring attention to potential complications and incomplete recovery. Furthermore, the evaluation of the four concussion cases on ImPACT provided a clear demonstration of how this computerised neuropsychological test was able to differentiate 'simple' from 'complex' concussions, thus providing a challenge to the recent Prague recommendations that states that neuropsychological testing is not necessary in all cases. The use of the ImPACT computerised neuropsychological test, administered and interpreted in the context of the athlete's relevant history, has in this preliminary study, provided a demonstration of its effectiveness as a key measure in the individual assessment and monitoring of concussive injuries in the school context. In this process, the interpretations gained from the neuropsychological test results seemed best supported by a combination of baseline scores and normative data derived from a South African sample.

REFERENCES

Almquist, J., Broshek, D., & Erlanger, D. (2001). Assessment of mild head injuries. *Athletic Therapy Today, 6* (1), 13-17.

Aubry, M., Cantu, R., Dvorak, J., Graf-Baumann, T., Johnston, K., Kelly, J. et al. (2002). Summary and agreement statement of the first international conference on concussion in Sport, Vienna. *Clinical Journal of Sports Medicine 12* (1), 6-10.

Calhoun, S. L. & Temple, U. ((2004). Clinical implications of the WISC-III processing speed index for special population. *Dissertatin Abstracts International: Section B: The Sciences & Engineering, 65* (4-B), 2140

CogSport (2002). *Science > reliability and validity*. Retrieved April 15, 2005, from, http://www.cogsport.com/html/science_reliability.html

Collie, A., Darby, D., & Maruff, P. (2001). Computerised cognitive assessment of athletes with sports related head injury. *British Journal of Sports Medicine, 35,* 297-302.

Collie, A., Maruff, P., Darby, D.G., & McStephen. (2003). The effects of practice on the cognitive test performance of neurologically normal individuals assessed at brief test-retest intervals. *Journal of the International Neuropsychological Society, 9,* 419-428.

Collie, A., Maruff, P., McStephen, M., & Darby, D.G. (2003). Psychometric issues associated with computerised neuropsychological assessment of concussed athletes. *British Journal of Sports Medicine, 37* (6), 556-559.

Collie, A., Maruff, P., McStephen, M., Darby, D. G., & McCrory, P. (2004) Statistical procedures for determining the extent of cognitive change following concussion. *British Journal of Sports Medicine, 38* (3), 273-278.

Collins, M. W., Grindel, S. H., Dede, D. E., Moser, D. J., Phalin, B. R., Nogle, S. et al. (1999). Relationship between concussion and neuropsychological performance in college football players. *Journal of the American Medical Association, 282* (10), 964-970.

Collins, M. W., Iverson, G.L., Lovell, M. R., McKeag, D. B., Norwig, J. & Maroon, J. (2003). On-field predictors of neuropsychological and symptom deficit following sports-related concussion. *Clinical Journal of Sports Medicine, 13,* 222-229.

Collins, M. W., Lovell, M. R., & McKeag, D. B. (1999). Current issues in managing sports-related concussion. *Journal of the American Medical Association,282* (24), 2283-2285.

Comerford, V. E. & Geffen, G. M., May, C., Medland, S. E., & Geffen, L. B. (2002). A rapid screen of the severity of mild traumatic brain injury. *Journal of Clinical and Experimental*

Neuropsychology, 24 (4), 409-419.

Echemendia, R. J., Putukian, M., Scott Mackin, R., Julian, L., & Shoss, N. (2001). Neuropsychological test performance prior to and following sports-related mild traumatic brain injury. *Clinical Journal of Sports Medicine, 11*, 23-31.

Edwards, D. J. A., Dattilio, F. M., & Bromley, D. B. (2004). Developing evidence-based practice: The role of case-based research. *Professional Psychology: Research and Practice, 35* (6), 589-597.

Erlanger, D., Feldman, D., Kutner, K., Kaushik, T., Kroger, H., Festa, J. et al. (2003). Development and validation of a web-based neuropsychological test protocol for sports -related return-to-play decision-making. *Archives of Clinical Neuropsychology, 18*, 293-316.

Erlanger, D., Kaushik, T., Cantu, R., Barth, J.T., Broshek, D.K., Freeman, J.R. et al. (2003). Symptom-based assessment of the severity of a concussion. *Journal of Neurosurgery, 98*, 477-487.

Field, M., Collins, M.W., Lovell, M. R., & Maroon, J. (2003). Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. *The Journal of Pediatrics, 142,* 546-553.

Fischer, J.M. & Vaca, F. E. (2004). Sport-related concussions in the emergency department. *Topics in Emergency Medicine, 26* (3), 260-266.

Grindel, S. H., Lovell, M. R., & Collins, M. W. (2001). The assessment of sport-related concussion. The evidence behind neuropsychological testing and management. *Clinical Journal of Sports Medicine, 11,* 134-143.

Guskiewicz, K. M., Bruce, S. L., Cantu, R. C., Ferrara, M. S., Kelly, J. P., McCrea, M., et al. (2004). National Athletic Trainers' Association position statement: management of sport-related concussion. *Journal of Athletic Training, 39* (3), 280-297.

Hanlon, R. E., Demery, J. A., Martinovich, Z., & Kelly, J. P. (1999). Effects of acute injury characteristics on neuropsychological status and vocational outcome following mild traumatic brain injury. *Brain Injury, 13* (11), 873-887.

Headminder (2001). *What is the CRT?* Retrieved on 4/1/05 from http://www.headminder.com/sites/crt/what_is_the_crt.html

Headminder (2003). *Test specifications.* Retrieved April 1, 2005 from http://www.headminder.com/site/crt/test_specs.html

Hinton-Bayre, A. D., & Geffen, G. (2002). Severity of sports-related concussion and neuropsychological test performance. *Neurology, 59*, 1068-1070.

ImPACT (2005). *Reliability and validity of the ImPACT test battery.* (Newsletter 1st quarter). Retrieved February 2005 from http://www.impacttest.com

Iverson, G. L., Gaetz, M., Lovell, M. R. & Collins, M. W. (2003). Cumulative effects of concussion in amateur athletes. *Brain Injury, 18* (5), 433-444.

Iverson, G. L., Lovell, M. R., & Collins, M. W. (2002a). Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) Normative Data Version 2.0 only. Retrieved May 2005 from http:// www.impacttest.com/dload/ImPACT21 usermanual.pdf

Iverson, G. L., Lovell, M. R., & Collins, M. W. (2002b, October). *Validity of ImPACT for measuring the effects of sports-related concussion.* Paper presented at the National Academy of Neuropsychology Annual Conference, Miami, FL.

Iverson, G.L., Lovell, M. R., & Collins, M. W. (2003). Interpreting change on ImPACT following sport concussion. *The Clinical Neuropsychologist, 17* (4), 460-467.

Iverson, G.L., Lovell, M. R., & Collins, M. W. (in press). Validity of ImPACT for measuring attention and processing speed following sports-related concussion. *Journal of Clinical and Experimental Neuropsychology*.

Kohler, R. M. N. (2004). Concussion in sport: practical management guidelines for medical practioners. *Continuing Medical Education, 22* (3), 122-125.

LeClerc, S., Lassonde, M., Scott Delaney, J., Lacroix, V. J., & Johnston, K. M. (2001). Recommendations for grading of concussion in athletes. *Sports Medicine, 31* (8), 629-636.

Lovell, M. R., Collins, M. W. (1998). Neuropsychological assessment of the college football player. *Journal of Head Trauma Rehabilitation, 13* (2), 9-26.

Lovell, M. R. & Collins, M. W. (2002). New developments in the evaluation of sports-related concussion. *Current Sports Medicine Reports, 1,* 287-292.

Lovell, M. R. & Collins, M. W., Grant, D., Field, M., Maroon, J., Cantu, R. et al. (2003). Recovery from mild concussion in high school athletes. *Journal of Neurosurgery, 98,* 296–301.

Lovell, M. R., Collins, M. W., Iverson, G. I., Johnston, K. M., & Bradley, J. P. (2004). Grade 1 or "ding" concussions in high school athletes. *American Journal of Sports Medicine, 32* (1), 47-54.,

Lovell, M. R., Iverson, G. L., Collins, M. W., McKeag, D., & Maroon, J. C. (1999). Does loss of consciousness predict neuropsychological decrements after concussion? *Clinical Journal of Sports Medicine, 9,* 193-198.

Macciocchi, S. N., Jeffrey, J. T., Alves, W., Rimel, R. W., & Jane, J. A. (1996). Neuropsychological functioning and recovery after mild head injury in collegiate athletes. *Neurosurgery, 39* (3), 510-514.

Makdissi, M., Collie, A., Maruff, P., Darby, D. G., Bush, A., & McCrory, P. (2001). Computerised cognitive assessment of concussed Australian Rules footballers. *British Journal of Sports Medicine, 35* (5), 354-360.

Maroon, J. C., Field, M., Lovell, M., Collins, M., & Bost, J. (2002). The evaluation of athletes with cerebral concussion. *Clinical Neurosurgery, 49*, 319-332.

Maroon, J. C., Lovell, M. R., Norwig, J., Podall, K., Powell, J. W. & Hartl, R. (2000). Cerebral concussion in athletes: evaluation and neuropsychological testing. *Neurosurgery, 47,* 659-672.

Mathias, J. L., Beall, J. A., & Bigler, E. (2004). Neuropsychological and information processing deficits following mild traumatic brain injury. *Journal of the International Neuropsychological Society, 10* (2), 286-297.

McAllister, T., & Arciniegas, D. (2002). Evaluation and treatment of postconcussive symptoms. *NeuroRehabilitation, 17,* 265-283.

McCrea, M., Kelly, J. P., Randolph, C., Cisler, R., & Berger, L. (2002). Immediate neurocogintive effects of concussion. *Neurosurgery, 50* (5), 1032-1042.

McCrory, P. R., & Johnston, K. M. (2002). Acute clinical symptoms of concussion. *Physician & Sports Medicine, 30* (8), 43-47.

McCrory, P. R., Collie, A., Anderson, V., & Davis, G. (2004). Can we manage sport related concussion in children the same as in adults? *British Journal of Sports Medicine, 38 (5),* 516 - 519.

McCrory, P. R., Johnston, K. M., Meeuwisse, W., Aubry, A., Cantu, R., & Dvorak, J. et al. (2005). Summary and agreement statement of the 2nd international conference on concussion in sport, Prague 2004. *British Journal of Sports Medicine, 39* (4), 196-204.

Nathan, M., Goedeke, R. & Noakes, T. D. (1983). The incidence and nature of rugby injuries experienced at one school during the 1982 rugby season. *SA Medical Journal, 64,* 132-137.

McKeever, C. K. & Schatz, P. (2003). Current issues in the identification, assessment and management of concussion in sports-related injuries. *Applied Neurosurgery, 10* (1), 4-11.

Pardini, D. & Lovell, M. (2005). *Test reliability and intraclass correlations.* Retrieved February 2005 from http://www.impacttest.com

Peloso, P. M., Carroll, L. J., Cassidy, D., Borg, J., von Holst, H., & Holm, L. et al. (2004). Critical evaluation of the existing guidelines on mild traumatic brain injury. *Journal of Rehabilitation Medicine, 43,* 106-112.

Phillips, S. M. (2003). Concussion: a review and update. *Athletic Therapy Today, 8* (5), 42-44.

Poirer, M. P. (2003). Concussions: Assessment, management, and recommendations for return to activity. *Clinical Pediatric Emergency Medical Journal, 4,* 179-185.

Powell, J. W & Barber-Foss, K. D. (1999). Traumatic brain injury in high school athletes. *Journal of the American Medical Association, 8,* 958-963.

Satz, P. (1993). Brain reserve capacity on symptom onset after brain injury: a formulation and review of evidence for threshold theory. *Neuropsychology, 7*, 273-295.

Satz, P. (2001). Mild head injury in children and adolescents. *Current Directions in Psychological Science,10,* 106-109.

Schatz, P. & Browndyke, J. (2002). Applications of computer-based neuropsychological assessment. *Journal of Head Trauma Rehabilitation, 17* (5), 395-410.

Schatz, P. & Zilmer, E. (2003). Computer-based assessment of sports-related concussion. *Applied Neuropsychology, 10* (1), 42-47.

Schnirring, L. (2001). How effective is computerized concussion management. *The Physician and Sportsmedicine, 29* (8), 11-16

Schnirring, L. (2004). New recommendations for concussion management. *The Physician and Sportsmedicine, 32* (12), 12-14.

Shuttleworth-Edwards, A., Border, M., Reid, I., & Radloff, S. (2004). South African Rugby Union. In M. R. Lovell, R. E. Echemendia, J. T. Barth & M. W. Collins (Eds). *Traumatic Brain Injury in Sports: An International Neuropsychological Perspective* (pp.149-168). The Netherlands: Swets & Zeitlinger.

Shuttleworth-Edwards, A., Radloff, S., Whitfield, V., & Mitchell, J. (2005). *ImPACT Normative data for South African high school boys age 16 to 18 years.* Manuscript in preparation.

Susco, T. M. (2003). Establishing concussion-assessment guidelines: on-field, sideline, and off-field. *Athletic Therapy Today, 8* (4), 48-50.

Terrell, T. R. (2004). Concussion in athletes. *Southern Medical Journal, 97* (9), 837-842.

Whitefield, V.(2005). *A study into the effects of acute and chronic mild traumatic brain injury,on cognitive functioning, amongst schoolboy rugby union players.* Unpublished doctoral thesis, Rhodes University, Grahamstown.

Wojtys, E. M., Hovda, D., Landry, G., Boland, A., Lovell, M., & McCrea, M. (1999). Concussion in sports. *The American Journal of Sports Medicine, 27* (50), 676-687.

Appendix A: Pre-Season Questionnaire

PRE-SEASON QUESTIONNAIRE (for all pupils)

(please hand into the secretary when completed)

Name: ______________________

Age: _________ **Date of Birth:** ________________

Grade: __________ **Class:** ___________

Contact number during the school term: ____________________

A. BACKGROUND INFORMATION

1. **Name:** ________________
2. **Surname:** ________________
3. **School:** __________________________
4. **Height:** __________m
5. **Weight:** _________ kgs
6. **Right handed:** ☐ **Left handed:** ☐ **(please tick)**
7. **Country of birth, other than South Africa:** _______________
8. **First Language:** _______________
9. **Second Language:** ________________
10. **Years speaking second language:** _________
11. **Please tick if you have received any of the following:**
    - ☐ Speech therapy
    - ☐ Attended special classes or remedial classes
    - ☐ Occupational therapy
    - ☐ Repeated any grades at school
    - ☐ Diagnosed with ADD or Hyperactivity
    - ☐ Diagnosed with a learning disability

12. Name your winter sport(s): ______________________________

13. What is your position? ________________

14. What team were you in last year? ________

15. How many years have you played at this level (not including this year)? ____

16. How many times have you been diagnosed with a concussion (i.e. dazed, dizzy or confused (however briefly) or unconscious)? ________________

17. If have sustained a concussion please complete the following:

Concussion	Date (approx. e.g. 1999)	Reason for Concussion e.g. Surfing, playing rugby, skate boarding, motor vehicle accident, falling off a ladder etc.)
1.		
2.		
3.		
4.		
5.		
6.		

18. From the list above, name the total number of concussions that resulted in a loss of consciousness.

____

19. List the total number of concussions that resulted in confusion.

____

20. List the total number of concussions that resulted in difficulty with memory for events occurring immediately after the injury.

____

21. List the total number of concussions that resulted in difficulty with memory for events occurring immediately before injury.

____

22. Please indicate whether you have experienced the following:

- ☐ Yes ☐ No Treatment for headaches by physician
- ☐ Yes ☐ No Treatment for migraine headaches by physician
- ☐ Yes ☐ No Treatment for epilepsy/ seizures
- ☐ Yes ☐ No History of Meningitis
- ☐ Yes ☐ No Treatment for substance/ alcohol abuse
- ☐ Yes ☐ No Treatment for psychiatric condition (depression, anxiety etc.)

Appendix B: Headmaster Consent Form

RHODES UNIVERSITY
DEPARTMENT OF PSYCHOLOGY

HEADMASTER CONSENT FORM

I, ____________________ headmaster of ____________________ have been informed of the nature of the research which will be conducted by Rhodes University MA student, Julia Mitchell, on the effects of concussion in school rugby.

I understand that:

1) The above mentioned student is conducting the concussion management research as a requirement for a MA degree at Rhodes University.

2) The research will involve the top three rugby teams in the 16-18 year age range, who will be assessed using scientifically validated computer-based neuropsychological programme, ImPACT. The programme includes a brief demographic questionnaire, a medical and concussion history as well as the neuropsychological test battery. The test battery involves the evaluation of cognitive functions such as memory, reaction time and processing speed which have been found to be highly sensitive to brain injury. The programme will take between 20-30 minutes to complete and all testing will be conducted in the school computer laboratories.

3) Follow-up assessments of concussed players will take place within 36 hours of injury and then again at 5 days, 10 days and 15 days post injury using different versions of the ImPACT programme. If a schoolboy has not returned to his preseason score by day 15 post injury, testing will continue at weekly interval until the symptoms resolve or until the end of the 2004 rugby season

4) This study does not interfere with or substitute for good medical practice. It is therefore advised that all schoolboys with concussion should be seen as soon as possible by their medical practitioner and should not return to contact sport for at least 3 weeks from the time of injury and thereafter on the advice of the medical practitioner.

5) Participation in the research is strictly voluntary and parents have the right to withdraw their sons from the study at any stage. Parents must contact the school in order to sign a withdrawal form should they not wish their sons to participate in the study.

6) The information collected on the individual schoolboys will be strictly confidential and will only be made available to the parents and/or a medical practitioner on request. This information may form part of the management decision in individual cases. However, the researcher will not be held accountable for medical decisions made by the medical practitioners or parents on the basis of that information.

7) Data arising out of this project will be used for thesis purposes only, but will be made available for future research in this area, while maintaining the anonymity of all participants.

I, hereby give consent for those pupils who will be participating in this research project to be tested by the above-mentioned researcher.

Signed: ____________________________ **Date:** ______________________

Appendix C 1: Covering letter for parents re: concussion in school sport

Dear Parents

CONCUSSION IN SCHOOL SPORT

In keeping with our goals to maximize the safety of sports players generally, and particularly in the contact sports where there is a known risk of concussion, we have given our support for a research project on sports concussion to be conducted at the school during 2004. This research will be conducted, under supervision, by an MA student from Rhodes University using a computerized management programme, ImPACT. This is a scientifically validated computerized screening system developed in the USA specifically for concussion management.

It is generally considered that computer-based screening of reaction times and memory function provides easily accessible, yet crucial information for concussion management especially with respect to return-to-play decisions. These types of programmes are already extensively in place in sports playing institutions in countries such as the USA, Australia and New Zealand. ImPACT, an American programme, is widely acknowledged as a leading instrument in this field.

Schoolboys in the top three rugby teams, in the 16-18 year age range, have been selected to participate in this research study. The boys will be tested before the rugby season starts, using the ImPACT programme. This will establish their baseline scores against which future test results can be compared, should they sustain a concussion during the 2004 rugby season. The tests are usually enjoyed by the boys and take between 20-30 minutes to complete. ImPACT programme also includes a brief demographic questionnaire, a medical and concussion history, and a symptom checklist, with relevance to the research.

There will be ongoing sports concussion monitoring through the winter season and appropriate intervention following the standard school procedure. In the event of a concussion, follow-up evaluation of concussed players will take place within 36 hours of injury and then again at 5 days, 10 days and 15 days post injury, using different versions of the ImPACT test. If a schoolboy has not returned to his baseline score 15 days post injury, testing will continue at weekly intervals until the symptoms resolve or until the end of the 2004 rugby season. All testing will take place on the school property. The data will be examined by the researcher at Rhodes University. The results of the research will be made available for further research in this field, while maintaining the anonymity of all the participants.

It is important to be aware that this study does not interfere with or substitute for good medical practice. We advise that all schoolboys with concussion should be seen as soon as possible by their medical practitioner and should not return to contact sport for at least 3 weeks from the time of injury and thereafter on the advice of the medical practitioner. The information collected on individual schoolboys will be strictly confidential and will only be made available to the parents and/or a medical practitioner on request. This information may form part of the management decision in individual cases. However, the researchers will not be held accountable for medical decisions made by medical practitioners or parents on the basis of that information.

We believe that it is in your son's best interest to participate in this concussion monitoring and risk prevention project although participation is voluntary and you have the right to withdraw from the entire project or part thereof. Indication of your desire to do so must be done by signing a withdrawal form before the ....2004, which will be made available by contacting the Sports Head. At the same time any further queries that you may have can be discussed.

Yours sincerely

(Head of Sport)

Appendix C 2: Brief to parents regarding concerns about child's participation in research

BRIEF TO PARENTS REGARDING CONCERNS ABOUT CHILD'S PARTICIPATION IN RESEARCH

We believe that it is in your son's best interest to participate in this concussion monitoring and risk prevention project, although participation is voluntary.

1. The parent has the right to withdraw the child from the entire project or any time during the research project.

2. Withdrawal of the child from the project must occur in writing. The parent must complete the withdrawal form below.

3. We wish to emphasize that the project is neither invasive nor harmful to the child's physical, mental and/or emotional well-being. For research purposes, the identity of the participants will be kept strictly confidential and individual data will be made available for clinical purposes only with parental permission.

4. By not participating in the project, in the event of a concussion, no base-line scores or concussion follow-up by the researchers will be available for that child.

5. Should your son sustain a head injury for any other reason, any deterioration in cognitive functioning would be more accurately assessed in relation to baseline data derived from the study.

WITHDRAWAL FORM

I, ____ hereby wish to withdraw my son

____ from participating in the school's concussion project.

I am aware of the possible negative consequences to my son's well-being in declining computer-based monitoring in respect of concussion.

SIGNED: ________________________________

DATE: ____________________

Appendix D: General information for pupils and pupil consent form

GENERAL INFORMATION FOR PUPILS AND PUPIL CONSENT FORM

Please take note of the following information which will be read out to you and explained by the tester, Julia Mitchell, who is conducting a research project on concussion management as a requirement for a MA degree at Rhodes University.

1. What we are doing here today is getting some basic information which will be of help to the school coach and doctors when managing the after effects of a head injury should any of you get concussed whilst playing rugby, or for any other reason, during the year. This is the latest way that sports concussion is being managed in other parts of the world such as the USA, Australia and New Zealand and is already in place for the Springboks and the All Black rugby teams. You will be using the ImPACT computerized concussion programme which is considered the leader in this field.

2. The programme consists of a brief demographic questionnaire, medical and concussion history, a symptom checklist and the test battery. The programme is computerized and should only take 20-30 minutes to complete.

3. The information collected will be totally confidential, and will only be looked at individually should you sustain a head injury. If someone is concussed they will be retested using different versions of this test at 36 hours after the injury, again at 5 days, at 10 days and at 15 days. These results will be compared with the preseason test score obtained today and in this way the person's recovery process can be closely monitored. If the person has not returned to their preseason score by 15 days after injury, testing will continue at weekly intervals until the symptoms have resolved. As these tests are very sensitive to head injuries the results will assist the doctor and coach in making more informed decisions on the severity of the injury and on return to play decisions. The researcher will only be acting in an advisory capacity and will not be taking responsibility for the final decision about return to play.

4. All testing will be carried out on the school premises. The information will be used for research purposes and the identity of the boys involved will not be made known.

5. It is VERY important to do your best and to be as accurate and honest as possible when you answer the questions. If the information you give at this time is not accurate, and/or you can't do your best on the tests for any reason, this might cause the doctor to make a wrong assessment of the seriousness of the head injury, and would not be of benefit to you medically. So, if at the end of this session, you believe you have not been able to do your best for any reason, please inform the tester. Reasons for not doing your best might be because you have a headache, are worrying about something else or have been distracted.

6. Please discuss any questions or concerns that you may have about the project with the researcher. Once your questions have been satisfactorily answered please complete the consent paragraph below.

I,______________________________, understand the nature of the research project as specified above. I understand that my participation in the research is strictly voluntary and that I have the right to withdraw from the study at any stage.

SIGNED:________________________________ DATE:__________________