# "Is Rugby bad for your intellect?"

# The effect of repetitive mild head injuries on the cognitive functioning of university level rugby players.

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# ABSTRACT

The study sought to determine whether there is evidence for the presence of residual (chronic) deleterious effects on cognition due to repetitive mild traumatic brain injury in top team university level rugby players, using ImPACT 3.0, Trail Making Test (TMT) and Digit Span. The initial sample of 48 participants was divided into groups; Rugby (n = 30) and Controls (n = 18), Rugby Forwards (n = 14) and Rugby Backs (n = 16). A reduced sample (N = 31) comprised of Rugby (n = 20) and Controls (n = 11), Rugby Forwards (n = 9) and Rugby Backs (n = 11). Comparative subgroups were equivalent for estimated IQ but not for age and educational level in the full sample; in the reduced sample there was equivalence for all three variables of age, education and estimated IQ. All cognitive test measures were subjected to independent t-test analyses between groups at the pre- and post-season, and dependent t-test analyses for Rugby and Controls at pre- versus post-season. Overall, the results implicated the presence of deleterious effects of concussive events on Rugby players in the areas of speed of information processing, working memory and impulse control. Significant practice effects were found on the TMT and Digit Span for controls, but not on ImPACT 3.0, supporting the use of this computer-based programme in the sports management context.

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# 1. INTRODUCTION

The objective of this study was to establish the following:

(1) Whether there is any evidence for the presence of residual deleterious cognitive effects of repetitive mild traumatic brain injury (cumulative concussions and sub-concussive episodes) in top team university level rugby players due to (a) a prior history of playing rugby for a number of years (high school into university) and (b) an eight month season of participation in rugby, potentially causing an overlay of additional acute or chronic effects.

(2) Whether rugby forwards would show significantly more cognitive impairment due to the above factors when compared with rugby backs.

(3) Whether the sensitivity the ImPACT neurocognitive composite scores are as sensitive to the above cognitive decrements as the well researched traditional paper and pencil tests of the Trail Making Test (parts A and B) and Digit Span (forwards and backwards).

Mild Traumatic Brain Injury (MTBI), alternatively referred to as concussion, is a common occurrence in sport and as the age and competence of the players increases so does the incidence of injury (Jordan, 1998). It is reported that there are one million traumatic brain injuries per year in the United States; 50 000 of these result in death; 70 000 – 90 000 result in permanent disability; and 300 000 are as a result of concussions in contact sports. Fifty percent are minor head injuries and eight deaths per year due to head injuries in American football are reported (Howard, 2004). Jacobson and Speechly (1988) reported that South Africa had seen an increase in rugby injuries in the previous 15 years, of which concussion was common, and this trend has shown no indication of abating. Not only are there confirmed concussions, but it is postulated that multiple sub-concussive events that are unreported may occur (micro traumatic brain injuries) and these may have cumulative effects (Rutherford, Stephens & Potter, 2003). The increasing possibility that there are cumulative effects of concussion is now a growing concern (Iverson, Gaetz, Lovell & Collins, 2003).

Concussions may involve potentially devastating immediate (acute) effects and also long-term (chronic) effects (Grindel, Lovell & Collins, 2001). In the acute condition, cognitive sequelae usually resolve within three months post-injury, and the effects which persist for longer than three months post injury may be considered chronic (Barth et al., 1989). In both these conditions, neuropsychological deficits after MTBI (as identified on objective testing) include impairments in processing speed of information, memory and attention, reaction time, planning and cognitive flexibility. The deleterious effect of concussion on such aspects of cognition is of relevance to scholars whose academic performance may be compromised in both the short and long-term. Return-to-play when a concussion is not recovered has inherent dangers for all athletes, who risk cumulative long-term neurocognitive dysfunction and either severe morbidity or death due to the Second Impact Syndrome where a second mild traumatic brain injury follows an initial unresolved brain injury (Bowen, 2003; Grindel et al., 2001; McCrory & Berkovic, 1998).

### 1.2 Classification of terminology and definitions

Numerous definitions of concussion abound in the literature (Binder, 1986). There is greater consensus on the definition of more severe head injuries than the minor head injuries (Satz, Zaucha, McCleary, Light, Asarnow & Becker, 1997). Kibby and Long (1996) report that the term ‘minor head injury’ is commonly used to indicate those suffering from traumatic brain injury of mild to moderate severity. Binder (1986) reports that mild head injury has traditionally referred to those head injuries where the period of Post Traumatic Amnesia (PTA) is relatively short and there is no structural damage to the skull or brain, and where the Glasgow Coma Scale (GCS) yields a score of 13 or more. Some studies have used one or more of these criteria while others have added criteria. Dacey and Dikman (1987) used the Glasgow Coma Scale score alone to determine the severity of a head injury. A Glasgow Coma Scale of 1 - 8 indicates a severe head injury, a score of 9 – 12 a moderate head injury and a score of 13 -15 a mild head injury (Dacey & Dikman, 1987). While the Glasgow Coma Scale is effective in evaluating severe head trauma it was never intended as a means of distinguishing between different types of mild injury and it therefore lacks the sensitivity for this task (Kraus & Nourjah, 1989; Schoenhuber & Gentilini, 1989).

The Mild Traumatic Brain Injury Committee of the Head Injury Interdisciplinary Special Interest group of the American Congress of Rehabilitation Medicine (Kibby & Long, 1996) developed a more formal definition that attempts to delineate both the upper and lower limits of MTBI, as follows:

“A patient with MTBI is a person who has had a traumatically induced physiological disruption of brain function as manifested by at least one of the following (i) any period of loss of consciousness (LOC), (ii) any loss of memory for events immediately before or after the accident, (iii) any alteration in mental state at the time of the accident (e.g. feeling dazed, disorientated or confused), and (iv) focal neurological deficit(s) that may or may

> not be transient; But where the severity of the injury does not exceed the following; a loss of consciousness of approximately 30 minutes or less; after 30 minutes, an initial Glasgow Coma Scale of 13-15; and PTA not greater than 24 hours" (p. 161).

Although this definition takes an important step by delineating both the upper and lower limits of MTBI, some difficulties still remain. Kibby and Long (1996) consider the lower limits proposed above as insufficient as they do not necessarily imply structural damage to the brain and this now includes any impact to the head, however mild, regardless of whether or not it has any consequences. Furthermore, they point out that in some respects this definition also combines mild and moderate TBI as several studies have defined MTBI as PTA under one hour and moderate TBI as PTA ranging from one to 24 hours. Kibby and Long (1996) draw attention to differences on outcome measures depending on the length of PTA. The result is that this definition covers a wide range of severity, making comparison with existing research difficult.

In the sports arena, where concussion tends to be the preferred term for MTBI, a series of further definitions have evolved. However, there has been a lack of an accepted definition due to the numerous limitations in accounting for the common symptoms present. In addition, relatively minor impact injuries that result in either persistent physical or cognitive symptoms have not been included in these definitions. In November 2001, the International Ice Hockey Federation (IIHF), the Federation Internationale de Football Association Medical Assessment and Research Centre (FIFA, F-MARC) and the International Olympic Committee Medical Commission (IOC), collectively called the Concussion in Sport group, organised the First International Symposium on Concussion which was held in Vienna. Here, seeking to transcend these limitations, the Concussion in Sport group developed an all encompassing definition for concussion, delineating it as a "complex pathophysiological process affecting the brain, induced by traumatic biochemical forces". Included in this definition, were several common features that "incorporate clinical, pathological, and biochemical injury constructs that may be used in defining the nature of a concussive head injury". These included the following (i) 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, (ii) concussion typically results in the rapid onset of short lived impairment of neurological function that resolves spontaneously, (iii) concussion may result in neuropathological changes but the acute clinical symptoms largely reflect a functional disturbance rather than a structural injury, (iv) concussion results in a graded set of clinical syndromes that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course, and (v) concussion is typically associated with grossly normal structural neuroimaging studies (Aubry et al., 2002, p. 6).

The Concussion in Sport group definition as delineated above incorporates most shortcomings in defining traumatic brain injury both severe and mild and is now commonly accepted. The Second International Conference on Concussion in Sport, held in Prague (2004) kept the same definition, only noting that in some cases post-concussive symptoms may be 'prolonged or persistent' (McCrory et al., 2005, p. 196). Another proposal put forward out of the Prague convention was that concussion may be categorised for management as either 'simple' or 'complex' (McCrory et al., 2005, p. 50). Simple concussions are defined as a concussive injury that progressively resolves without complications over 7 – 10 days, and complex as those cases of concussion which are at greater risk for complications where athletes suffer persistent symptoms which lead to prolonged cognitive impairment. This category may include athletes who suffer multiple concussions over time where repetitive concussions occur with less force (sub-concussive episodes) (McCrory et al, 2005). This key development does not highlight any new clarifications with regard to defining concussions per se. Rather, it serves to highlight the fact that this latter group needs to be managed in a multidisciplinary manner where the inclusion of on-field predictors and formal neuropsychological testing is an important feature in the return-to-play decision making process.

### 1.3 Incidence of concussion in sport

*Incidence in American football and ice-hockey*

The high incidence of concussion in contact sports is well documented (Guskiewicz et al., 2003) where approximately 300 000 sport-related concussions occur annually in the United States with the likelihood of serious sequelae increasing with repeated head injury. Studies from the 1970's report concussion rates as high as 15% to 20% for all players in a season of American football. In the 1980's annual incidences were reported as 10% and more recently incidence rates have decreased to between 3.6% and 5.6% (Guskiewicz et al., 2003) due to the implementation of the Safety in Athletic Equipment Protection Standards. Lovell and Collins (2002) report the estimated 300 000 sports related injuries per year in the United States as conservative, due to the reluctance of players to leave the field during a match because of such an injury. There is also a tendency amongst players to deny the presence of head injuries, and this fact was reiterated at both the First and Second International Symposia on Concussion in Sport (Aubry et al., 2002; McCrory et al., 2005). Williamson, Bradley, Schisler and Goodman

(2004) showed that under reporting of concussions to ice-hockey's governing bodies both by players and bench staff is a significant problem. They noted a reporting of 0.0017% (for the 2003/4 season) which they suggested was a gross underestimate compared with the true rate. Research carried out by Lovell, Collins, Bradley, van Kampen, Moritz and McClincy (2004) found that because of under-reporting of concussive symptomology, reliance on player reported symptoms could result in premature return-to-play. These factors suggest the incidence of MTBI to be much higher than is actually reported.

*Incidence in Soccer*

Soccer is the most popular and widespread sport in the world, with an estimated 242.5 million players in 204 countries, with a significant number of head injuries resulting in trauma to the brain (Rutherford et al., 2003). Levin, Eisenberg and Benton (1989) reported that in one season, 91% of the players sustained an injury at some stage. Although most soccer injuries are to the ankle, knee or groin, the lower extremities (McMaster & Walker, 1978; Sandelin, Santavirta & Kiviluoto, 1985; Wong & Hong, 2005), a substantial proportion are head injuries relating to trauma to the brain such as occur in MTBI (Barnes, Cooper, Kirkendall, McDermott, Jordan & Garrett, 1998; Boden, Kirkendall & Garrett, 1998). Clear research on the incidence of MTBI in soccer is limited due to confounding variables not being controlled. These include the differences in the definitions of concussion and time the injury is sustained, that is during competition or normal training, and position of play. Hunt and Fulfor (1990) suggest that centre backs and centre forwards are likely to sustain the majority of head injuries, and this is most likely to occur during crosses (passes to a centre forward) when there is competition to head high balls (Kirkendall, Jordan & Garrett, 2001). Additionally, Bernstein (1999) and King (1997) report that increases in the number of head injuries in soccer rises due to the residual effect of concussive injury. More reliable empirical research is needed to track both incidence and neuropsychological impairment as a consequence of soccer related concussions. At present, there is no reliable definitive evidence that such impairment occurs as a result of general football heading (Rutherford et al., 2003).

*Incidence in Rugby*

Rugby Union, played in countries such as South Africa, New Zealand, Australia, France, England and Japan, is identified as one of the world's most dangerous sports due to the speed of play and the number of body collisions due to the nature of tackling (Hillis, McIntyre, McClean, Goodwin & McKenna, 1994; Wekesa, Asembo & Njororai, 1996). Incidence rates are considered to be reaching epidemic proportions due to the inherent dangers of the sport (Wekesa et al., 1996).

The incidence of overall injury for the three types of football played at Eton indicates that Rugby Union is the most dangerous (Briscoe, 1985). The injury rate for professional Rugby Union players is 50% higher than the highest rate for Rugby League (Garraway, Lee, Hutton, Russell & McCleod, 2000). Similar research conducted by Walker (1985) reports Rugby Union injuries to be higher than Rugby League when compared with serious injuries. Research on Rugby Union across cohorts of adult and schoolboy studies indicates that head, face and neck injuries make up a large percentage of all injuries (Macleod, 1993; McKenna, Borman, Findlay & de Boer, 1986; Myers, 1980; Nathan, Goedeke & Noakes, 1983; Roux, Goedeke, Visser, van Zyl & Noakes, 1987; Roy, 1974; Ryan & McQuillan, 1992; van Heerden, 1976). The number of injuries is repeatedly shown to be between 25-30%. Three studies allude to figures for injuries as high as 37-52% (McKenna et al., 1986; Myers, 1980; Seward, Orchard, Hazard & Collinson, 1993). Seward et al. (1993) report the incidence of head and neck injuries as 37.3% for Rugby Union, 28.5% for Rugby League and 14.4% for Australian Rules football. Furthermore, in terms of positional influences and concussion, it is confirmed that for rugby, as with football at adult level, forwards sustain a significantly higher frequency of injuries per se. More injuries are sustained to the head and necks than to backs (Davies & Gibson, 1978; Gissane, Jennings, Cumine, Stephenson & White, 1997; Jakoet & Noakes, 1998; Lingard, Sharrock & Salmond, 1976; Seward et al., 1993). Nathan et al. (1983) identified the percentage of concussion during a single rugby season at a South African high school to be 21.5%, and with definitive central nervous system involvement. Using self-reports Shuttleworth-Edwards, Ackerman, Beilinsohn, Border and Radloff (2001) identified an average historical incidence of 2.3 concussions (range 0-7) per rugby playing schoolboy in a survey of three South African school’s top teams. This compares with an average incidence of only 0.4 (range 0-1) for an equivalent group of field-hockey players.

Wills and Leathem (2001) report that in New Zealand, rugby union accounts for the highest rate of sports-related brain injury. They identified that in one season of New Zealand club rugby, 30% of players reported at least one central nervous system related head injury. These figures however are likely to be much higher because the number of patients who are rendered unconscious briefly, and do not seek medical attention is unknown. In addition, because of the apparent lack of symptomology, players are reluctant to leave the field during a match because of such an injury. There is also a tendency amongst players to deny the presence of head injuries. This fact was reiterated at both the First and Second International Symposia on Concussion in Sport, and was discussed earlier in section 1.3 (Aubry et al., 2002; McCrory et al., 2005). These factors suggest the incidence of MTBI to be much higher than is actually reported. It is then clear from the above that players of Rugby Union are at much greater risk than other contact sports for concussive head injuries.

### 1.4 Physiological consequence

As described earlier in section 1.2 concussion is a closed head injury and can range in severity from mild to moderate to severe (Levin, Benton & Grossman, 1982). It is the result of trauma to the head which causes linear or rotational acceleration of the brain (as when a moving object collides with a stationary or slower moving head), or deceleration (as when a moving head and body are impacted upon by a stationary or slower moving object) (Levin et al., 1982). Both linear and rotational acceleration of the brain usually co-exist or follow on from one another in a closed head injury (Levin et al., 1982). This causes the brain to move forwards in the skull, where the frontal lobes strike the inside of the skull, and sideways movement where the brain strikes the temporal parts of the skull. This results in contusions, stretching and tearing of the neurons in the brain stem and throughout the cerebral white matter and lower brain structures, which leads to hemorrhaging from ruptured blood vessels (Lezak, Howieson & Loring, 2004). Diffuse axonal injury results from shear strain and is the primary mechanism proposed to account for damage and subsequent behavioural dysfunction in mild head injury (Anderson, 1996; Hovda, Le & Lifshitz, 1995; Wojtys et al., 1999).

Return-to-play when a concussion is not recovered has inherent dangers for all athletes due to the risk of cumulative long-term neurocognitive dysfunction and either severe morbidity or even death due to Second Impact Syndrome. Specifically, it is postulated that when the brain is in an already vulnerable state, it is more vulnerable to a second insult, thereby increasing the risk of second impact syndrome (Bowen, 2003; Grindel, Lovell & Collins, 2001; McCrory & Berkovic, 1998; Saunders & Harbaugh, 1984). This comprises a rapid cerebral edema and herniation after a second head injury, with a mortality rate close to 50% and morbidity rate approaching 100% (Proctor & Cantu, 2000). The second impact may be minor and be due to a rotational injury involving a blow to the chest, side or back; or an indirect rotational acceleration of the brain. The athlete often appears stunned but does not lose consciousness (Bowen, 2003). Within seconds of the second impact, the athlete may collapse to the ground, semi comatose, with rapid pupil dilation, lack of eye movement and respiratory failure. The pathophysiology of second impact syndrome is believed to stem from disordered auto-regulation of the brain's blood supply and the typical time from second impact syndrome to brain stem failure is rapid, estimated 2 to 5 minutes (Cantu, 1998). Cantu (1998) cites cases of second impact syndrome in athletes ranging in age from 17 to 24 years, where all athletes suffered a mild concussion and then a second relatively minor head trauma, which were refractory to medical treatment. McCrory and Berkovic (1998), cite definite and probable cases of second impact syndrome in males ranging between 16 and 24 years old. These findings are of significance to the present study as participants in the rugby cohort all fell within this age range.

Further, animal research has shown that concussion may be more neuronal with chronic cognitive implications. Wojtys et al. (1999) identified that in animal models with head injury resulting in concussion and associated reduction in cerebral blood flow, there is extensive neuronal cell loss. This injury-induced-vulnerability is the major concern for management of sports concussion and return-to-play guidelines, and hence is not only confined to second impact syndrome. The danger in this state is that the neurovascular system has an increased demand for energy-rich glucose to re-establish its normal chemical environment (homeostasis). If this is not maintained, the altered environment may result in neuronal loss and this has chronic implications for cognitive functioning. Similar research conducted by Hovda et al. (1995), indicates that this too is seen after MTBI and that the time course of events appears to be longer in human patients. Metabolic depression may even present up to one year after injury (Wojtys et al., 1999).

The dangers of incurring a second insult to a vulnerable brain, has raised concerns about return-to-play to sport prematurely. In the light of these inherent dangers, concussion grading scales were developed to help overcome the deleterious consequences of second impact syndrome.

## 1.5 Grading Scales

Concussion grading scales were initially defined by Cantu (1988), the Colorado Medical Society (1991) and Maroon, Field, Lovell, Collins & Bost (2002). These concussion grades developed out of the traditional approach which used loss of consciousness as the primary measure of injury severity, which is now acknowledged as a limitation in assessing the severity of concussive injury. Moreover, the Concussion in Sport group definition as described in section 1.2 (p. 3) is seen to incorporate the shortcomings of the criteria based on the alterations in consciousness (Glasgow Coma Scale), the changes in orientation and memory (i.e. the length of post traumatic amnesia) and the duration of unconsciousness (Satz et al., 1997). The grading systems each have management recommendations depending on the severity of the grade (Collins et al., 1999). Grading scales are therefore recognised in their attempt to help define and characterise injury severity, but no single system is presently endorsed by the Concussion in Sport group. It is rather recommended that combined measures of recovery should be used to help define, classify and diagnose concussion on an individual basis. This is due to the fact that there is limited published evidence to show that concussion injury severity correlates with the number and duration of acute concussion signs and symptoms and degree of impairment on objective neuropsychological testing (McCrory et al., 2005). Neuropsychological testing has been shown to be of value in concussion evaluation (Collins et al., 1999; Collie, Maruff, McStephen & Darby, 2003; Grindel et al., 2001; Lovell, Collins, Iverson, Field et al., 2003) as cognitive recovery may precede or follow clinical symptom resolution. Neuropsychological assessment therefore should be an important component in any return-to-play protocol, although return-to-play should not be based solely on this assessment. It should rather form part of a multidisciplinary approach which includes on-field predictors and baseline pre-injury neuropsychological testing (McCrory et al., 2005).

### 1.6 Neuropsychological testing

Neuropsychological testing is considered to be the most sensitive method for the evaluation of both acute and chronic cognitive effects following concussion, and a crucial part of the medical management of sports concussion (Aubrey et al., 2002; Lovell, 2002; McCrea, Kelly, Randolph, Cisler & Berger, 2002). Traditional measures used to assess the neurocognitive effects of concussion involve paper and pencil instruments. However, such traditional neuropsychological measures are impractical for addressing sports concussion issues, and for the large scale administration required. They are time consuming and require skilled administration in a one-on-one setting (Bleiberg, Kane, Reeves, Garmore & Halpern, 2000). Computer-based neuropsychological instruments that identify acute and chronic effects following concussion have recently been developed, and are substantially less time-consuming. The development of these test batteries has eased the administration of and ability to obtain baseline test data on a large number of athletes in a short period of time, for normative levels of neurocognitive functioning for individual athletes. Practice effects must also be considered when administering neuropsychological tests. To help overcome this effect clinically, equivalent forms need to be used whenever possible. To eliminate this problem, computer-based programmes have developed multiple forms, which can then be used to evaluate the same cognitive functions. They then show significant advantages for the monitoring of concussion recovery when incorporated as part of the medical management (Guskiewicz et al., 2004). This has led to an increase in the use of computer-based testing and a decrease in traditional measures to assess the neuropsychological effects of MTBI (McCrea et al., 2002). This has in turn promoted the establishment of large scale data bases that allow the investigation of issues that surround diagnosis and treatment, simplifying assessment of acute and chronic cognitive dysfunction. Test batteries have been designed to assess domains of cognitive abilities, which are most sensitive to change after concussion. These include cognitive processing, working memory, learning and memory, attention and concentration, executive functioning and verbal fluency (Guskiewcz et al., 2004). A number of computer-based systems have been developed and show promise, especially for concussion management in the acute phase (Schnirring, 2001). These consist of CogSport (originating in Australia), HeadMinder (Concussion Resolution Index), ANAM (Automated Neuropsychological Assessment Metrics and ImPACT (Immediate Post-concussion Assessment and Cognitive Testing) (originating in the United States). A discussion of these four systems follows below.

*CogSport*

CogSport is a computer-based neuropsychological test battery that deviates from the traditional paper and pencil tests and makes use of a pack of playing cards as a visual stimulus to evaluate changes in cognitive functioning. These changes are tracked in a series of five cognitive tests measuring reaction time, decision making, sustained and divided attention, new learning and short-term and working and incidental memory, adaptive problem solving spatial abilities and decision making (Collie et al., 2003). CogSport has been based on scientific studies of reliability and validity and shows correlations with conventional tests used in post-concussion medical examination (Schatz & Zilmer, 2003). A study by Makdissi et al. (2001), on Australian footballers, sought to determine the sensitivity of CogSport cognitive tests to sports related concussion. Pre-season baseline assessments were conducted on 240 athletes using CogSport and two paper-and-pencil tests (Digit Symbol Substitution and Trail Making Tests). Results showed greater sensitivity to concussion injuries obtained from a simple reaction test from the CogSport battery than from the two traditional paper and pencil tests (Makdissi et al., 2001). However, criticisms of this battery are that it is not based on well researched neurological test stimuli and that the results of CogSport are analysed in Australia via e-mail, thereby limiting its accessibility for research studies. Additionally, it does not have a symptom checklist and some evidence of practice effects have been found over a brief test interval, where the suggestion of the use of playing cards may effect outcome in athletes who have had previous exposure to card games (Collie et al., 2003).

*HeadMinder*

Comparatively, HeadMinder is a concussion management system which is based on traditional paper and pencil tests, and has also been used as a key component in the assessment of sports related concussion and the return-to-play decision making process. The system has a Concussion Resolution Index, which was designed to track resolution of neurophysiological symptoms following sports-related concussion and focuses on assessing cognitive functions associated with those symptoms. The Concussion Resolution Index also uses a number of short subtests that measure reaction time and speeded decision-making, both of which can be affected by changes in speed of information processing. These three factors are empirically derived from the subtests (i) simple reaction time, (ii) complex reaction time, and (iii) processing speed (Erlanger, Saliba, Barth, Almquist, Weberight & Freeman, 2001). The Concussion Resolution Index correlates with traditional neuropsychological face-to-face tests that assess speed of information processing and are known to be sensitive to post-concussive symptoms; Trail Making Test A and B, Grooved Pegboard, Symbol Digits Modalities Test and Wechsler Adult Intelligence Scale-Third Edition Subtests of Symbol Search and Digit Symbol Substitution. The Concussion Resolution Index measures response time more accurately than traditional paper and pencil test measures, and it has the ability to statistically account for practice effects over multiple tests administrations. Good test-retest reliabilities for Concussion Resolution Index summary indices are reported for processing speed, simple reaction time and complex reaction time. The criticism of HeadMinder is that it is limited in the range of cognitive domains it assesses, namely reaction time and processing speed, and due to the fact that it does not have a symptom checklist which then disregards the athletes complete symptom presentation at the pre, post and concussion testing sessions.

*ANAM*

There is limited information available on the Automated Neuropsychological Assessment Metrics (ANAM) which was designed for emphasis on both clinical and experimental applications which require repeated measures The ANAM consists of a large pool of test items together with pseudorandomisation techniques which give each test a large number of multiple forms, and testing of cognitive domains such as; simple reaction time, speed of motor response, attention and concentration, visual memory, working memory and visuo-spatial processing (Reeves, Kane, Winter, Raynsford & Pancella, 1995). This permits the ANAM to be used for extended baseline testing and for monitoring performance over extended periods. The ANAM battery has shown to correlate with traditional neuropsychological tests such as the California Verbal Learning Test. The ANAM has also been shown to assess similar constructs to those assessed by the Paced Auditory Serial Addition Test, The Trail Making Test B, Stroop C-W and the Hopkins Verbal Language Test (Bleiberg et al, 2000). Criticism of this battery is that its actual sensitivity to concussion has not yet been fully demonstrated and it is the subject of ongoing research (Bleiberg et al., 2000).

*ImPACT*

The ImPACT neuropsychological test battery has developed and evolved from the first version 1.0 (released in 1999) to version 4.0 (due to be released in 2006) through collaborative research, by its many users as a key component for the evaluation of concussion. With regard to ImPACT 3.0, the most up to date version available at present, and the version used in this study, the basic cognitive battery has remained the same as versions 1.0 and 2.0. However, version 2.0 saw a refinement over 1.0 with the addition of a visual memory composite, and version 3.0 has an additional refinement with the aid of a Reliable Change Index (RCI), where age and gender referenced percentiles are automatically printed within the report. Additionally, the Reliable Change Index is used to compare the athlete’s baseline score with subsequent testing for clinically significant scores with regard to the effects of concussion. The Reliable Change Index therefore allows more precise determinations of deterioration, improvement and recovery following MTBI (Iverson, Lovell, Collins & Norwig, 2002).

With regard to the 3.0 battery, it has been designed as a series of six individual test modules that measure aspects of cognitive functioning, and is used in its ability to test those domains of cognitive functioning which have been shown to be sensitive to change after concussion, namely processing speed, visual processing, memory, attention, reaction time and impulse control. The domains have been organised into six modules: 1) Word memory measuring attentional processes and verbal recognition memory, 2) Design Memory measuring attentional processes and visual recognition processes, 3) X’s and O’s, this module measures visual working memory, visual processing speed and visual memory, 4) Symbol Matching measuring visual processing speed, learning and memory), 5) Colour Match measuring impulse control and response inhibition), and 6) The Three Letters module, which measures working memory and visual motor response speed. The six modules are arranged to produce five composite scores in the areas of: 1) Verbal Memory, 2) Visual Memory, 3) Visual Motor Speed, 4) Reaction Time, and 5) Impulse control.

In addition to investigating a series of cognitive modalities such as processing speed, memory, reaction time and impulse control, it uses composites, which are based on well researched neuropsychological tests. The battery also includes a post-concussive symptom checklist. ImPACT 3.0 appears to be the most comprehensive of the systems in terms of traditional neurocognitive test measures, with the largest research base, and it has shown excellent reliability and strength in validity studies. Additionally, it is not web-based and is therefore available for research in South Africa where it is being used for a series of studies on sports concussion at Rhodes University, including the present study. A discussion of its reliability and validity is described below.

## 1.7 Reliability of ImPACT

Studies evaluating the test-retest reliability of ImPACT 1.0 show that it is a stable measure with good consistency, and is also stable across multiple administrations (Lovell & Collins, 2001; Lovell & Collins, 2002). In a study on 24 high school athletes, ImPACT 1.0 was administered four times, two to eight days apart. The memory index yielded test-retest correlation coefficients ranging from 0.66 to 0.85 between test session 1-2, 2-3 and 3-4. Test-retest correlation coefficients for the processing speed index across the same assessment comparisons ranged from 0.75 to 0.88. The reaction index had test-retest correlation coefficients ranging from 0.62 to 0.66. While the reaction time index was highly consistent across all of the testing sessions, the memory and process reactions tended to show some slight variability in that the correlation between times 1-2 was slightly weaker than between 2-3 and time 3-4. It appears that performance on these indices improved after the first testing session with little practice effect after additional administrations. ImPACT 1.0 was therefore designed to reduce practice effects through randomisation of stimuli presentation. This is an essential feature of the design because the battery is intended to be used repeatedly over short intervals (Iverson, Lovell, Collins & Norwig, 2002).

## 1.8 Validity of ImPACT

Studies executed on ImPACT have demonstrated that it has the ability to separate injured from age-matched non-injured control participants who suffer from even ‘mild’ concussions. This constitutes criterion-related validity, (Iverson, Gaetz, Lovell & Collins, 2005; Iverson & Lovell, 2002; Lovell, Collins, Iverson, Field et al., 2003). One particular study focused specifically on memory processes, and showed significant differences in performance on the ImPACT 1.0 Memory Composite, between 64 concussed and 24 non-concussed high school athletes at 36 hours and at four and seven days post injury. An additional study that included Memory, Reaction Time and Processing Speed Composites from ImPACT 1.0, found significant differences between baseline testing and post-injury performance in a group of high school athletes who had suffered mild TBI, with no LOC and who had reported being symptom free within 15 minutes post injury. Evaluation 36 hours post-injury of a sample of 43 high school athletes exhibited a significant decline in memory, an increase in reaction time and an increase in post-concussive symptoms, relative to their own baseline studies conducted pre-injury (Iverson, Lovell & Collins, 2002). These studies demonstrate the sensitivity of the ImPACT 1.0 test battery for mild TBI and also serve to highlight the need for ongoing evaluation of concussed athletes for evolving post-concussive signs and symptoms.

The battery has also been found to correlate with overall outcome following MTBI. Collins, Iverson, Lovell, McKeag, Norwig and Maroon (2003), found that the presence of accepted on-field markers of concussion such as retrograde and anterograde amnesia were strongly related to a significant deterioration (a 10 point increase in symptoms from baseline or a 10 point decrease on the Memory Composite score from baseline) at two days post-injury. Odds ratios revealed that athletes demonstrating a poor presentation were over 10 times more likely ($p < .001$) to have exhibited retrograde amnesia when compared with athletes exhibiting good presentation. Similarly, athletes with a poor presentation two days post injury were over four times more likely to have exhibited post traumatic amnesia and at least five minutes of mental status change. Further, performance on ImPACT has been found to relate closely to subjective symptoms following concussion. Iverson, Gaetz, Lovell and Collins (2004b) examined ImPACT version 2.0 test data from 110 concussed high school athletes who underwent neuropsychological testing within five to ten days post injury. Athletes who reported ‘fogginess’ at the time of testing demonstrated significantly slower reaction times, reduced verbal and visual memory performance and slower reaction time at one week post injury, compared to the group that did not report ‘fogginess’ (p. 6).

With regard to construct validity, it was demonstrated that a relationship between ImPACT composite scores and traditional measure such as Symbol Digits Modalities Test (SDMT) existed (Iverson, Lovell et al., 2002; Iverson, Lovell & Collins, in press). A sample of 72 amateur athletes was seen within 21 days sustaining a sports related concussion. It was shown that the SDMT correlated most highly with the processing speed (0.70) and Reaction Time (-0.60) composites from ImPACT. Additionally, the composite scores from ImPACT and the SDMT were subjected to exploratory factor analysis, revealing a two-factor solution interpreted as Speed/Reaction Time and Memory. Iverson, Lovell et al. (2002) interpreted these findings as indicative of the Processing Speed Composite, Reaction Time Composite and Symbol Digits Modalities Test as measuring a similar underlying construct in this sample of concussed amateur athletes.

In another study designed to assess the convergent and discriminant validity of ImPACT, Iverson et al. (2004b) evaluated the relationship of the ImPACT 2.0 composite scores to the Symbol Digits Modalities Test, Trail Making Tests A and B and to the Brief Visual Spatial Memory Test-Revised (BVMT-R) total and delayed memory scores. Twenty-five concussed high school and college athletes (mean age = 17.4 years) were tested within 20 days post-injury. A multitrait-multimethod approach was applied to examine specific pairs of test scores. The monotrait-monomethod was illustrated by the medium to high correlations between the Visual and Verbal Memory Composites from ImPACT ($r = 0.75$), Trail Making Tests A and B and Symbol Digits Modalities Test ($r = -0.70$) and the total score and the delayed recall score from the BVMT-R ($r = 0.62$). The monotrait-heteromethod was illustrated by the medium correlations between the BVMT-R total score and the Verbal and Visual Memory Composites from ImPACT (both r's = 0.50), and the high correlations between the delayed memory score from the BVMT-R and the two memory composites (both r's = 0.85). There were also medium correlations between the ImPACT 2.0 Processing Speed and the Trail Making Test A ($r = -0.49$), Trail Making Test B ($r = -0.60$), and the Symbol Digits Modalities Test ($r = 0.68$). Overall, ImPACT composite scores demonstrated the expected relationships with more traditional neuropsychological tests. Furthermore, the correlations between ImPACT 2.0 test scores and scores on non-computer-based tests designed to measure specific aspects of neurocognitive functioning (memory or neurocognitive speed) were generally higher than those reported for other batteries that have been utilised with athletes such as the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) (Lovell & Collins, 1998).

The cross-validation in the construct validity studies cited above serves to affirm the potential sensitivity of both ImPACT as well as the traditional measures tapping processing speed such as the Trail Making Tests and Symbol Digit Modalities Test, to the effects of concussion. In respect of such traditional measures of processing speed, this supposition concurs with prior research on rugby that has isolated persistent deleterious effects on cognition due to participation in the sport using the Trail Making Test and Digit Symbol Substitution (Shuttleworth-Edwards et al., 2004; Shuttleworth-Jordan et al., 1993). In both these studies however, a digits backwards test (tapping verbal working memory) also revealed discriminatory ability between rugby and controls, whereas there appear to be no studies in which ImPACT 3.0 (or any of the above cited computer-based programmes) has been conducted in association with Digit Span. Thus for the purposes of the present research it was decided to combine the use of Impact with one traditional test of processing speed, the Trail Making Test, as well as to incorporate a verbal working memory component by means of the Digit Span Test. These tests will therefore be discussed in more detail below.

### 1.9 Trail Making Tests A and B

The Trail Making Test is a test of scanning and visuo-motor tracking, divided attention and cognitive flexibility and is particularly sensitive to the effects of brain injury, especially Part B (Collins, Grindell et al., 1999; Lezak, 1995; Lovell & Collins, 1998; Lovell, Iverson, Collins, McKeag & Maroon, 1999), and is also well established in documenting brain injury (Reitan, 1958). Leininger, Gramling, Farrell, Kreutzer and Peck (1990) found using this test that patients with MTBI are slower than those of control subjects and slowing increases with the severity of the damage. Several other studies using the Trail Making Test have examined the sensitivity of attention measures in patients with traumatic brain injury, although not in athletes (Cicerone, 1997; Schmidt, Trueblood & Merwin, 1994; Wong, 1999). Schimdt et al. (1994) reported sensitivities ranging from 17% for Trail Making Test A. Wong (1999) reported sensitivities ranging from 41.6% for Trail Making Test A and 58.3% & for Trail Making Test B. These studies however lacked a comparison sample and hence made it difficult to determine the specificity of the test findings. Cicerone and Azulay (2002) sought to address these shortcomings in a study on subjects (non-athletes) with persistent symptoms (chronic 3 – 42 months) following MTBI and compared them with normal control subjects. These authors found that their highest accuracies were obtained with the Trail Making Test A, Paced Auditory Serial Addition Test (PASAT), Continuous Performance Test of Attention (CPTA) and the Stroop-Colour subtest, which were likely to reflect common clinical practice for identifying impaired functioning. They added that the Trail Making Tests had good specificity in ruling in the presence of impairment and hence confirmed the presence of attention impairments, and with a 90% confidence on Trail Making Test A.

### 1.10 Digit Span

The digit span comprises two different tests, digits forward and digits backwards, each of which involves different mental activities which are affected differently by brain damage. Digits forwards tests immediate verbal memory, and is primarily a test of efficiency of attention or ‘freedom from distraction (Kaufman, Mclean & Reynolds, 1991; Lezak et al., 2004). The digits backwards test involves storing data while manipulating it mentally and taps working memory function (Lezak et al., 2004). Of significant importance is that digits backwards is particularly sensitive to diffuse damage as might be expected in a closed head injury, which occurs during contact sport with players of rugby union. Due to digits forwards not being as sensitive as digits backwards to the effects of diffuse damage, it is expected to remain stable relative to the backwards span in the presence of diffuse damage (Lezak et al., 2004). Relative to a single concussive event, the digit span forwards of some patients, has been shown to fall below normal levels after MTBI, and then return to normal levels (Lezak, 1979).

### 1.11 Effect of repetitive MTBI on cognitive functions

Objective cognitive decline with or without the presence of post-concussive symptoms are uncontested acute consequences of concussion, and this appears to hold true for individuals with the mildest (Grade 1) level of concussion (Lovell, Collins, Iverson, Johnson & Bradley, 2003). Research confirming the presence of long-term chronic effects following a single concussive episode is less definitive. Bohen and Jolles (1992) tested symptomatic patients with MTBI at six months post injury and found deficits in selective and divided attention relative to an asymptomatic group. These results suggest that, although the majority of patients may recover functionally from single uncomplicated MTBI, a small but significant number do experience persisting cognitive deficit, up to at least 22 months post head injury. In sport, the risk for long-term problems is rarely associated with a single concussion (Iverson et al., 2003). It is noted, that multiple concussions, particularly within a short space of time, have been shown to result in long-term chronic effects (Grindel et al., 2001). As exposure to multiple concussions is a general feature of a contact sport such as rugby, extended exposure to such sport increases a player’s risk of developing these long-term chronic effects. There is now growing evidence to support the deleterious chronic effects of MTBI in the field of contact sports, including Australian Rules football, American football, Rugby League and in South Africa in Rugby

Union, with permanent brain injuries due to multiple concussions being reported in ice-hockey players (Grindel et al., 2001; Iverson, Gaetz, Lovell & Collins, 2002). More recently, MTBI in sport and the effect of repetitive MTBI has been witnessed as numerous professional athletes have had their careers prematurely ended due to these injuries (Guskiewicz et al., 2003; Iverson et al., in press).

A literature review on concussion reveals numerous investigations on the acute effects of concussion on athletes, especially American football, ice-hockey and soccer. There is however a growing neuropsychological focus on the chronic effects of MTBI especially in football (soccer), leaving a need for increased research in the area of American Football and Rugby Union.

*Soccer*

Jordan, Green, Galantly, Mandelbaum and Jabour (1996) and Matser et al. (1999) point to an association between chronic neuropsychological effects as a result of head trauma in soccer. Matser et al. (1999) using traditional paper and pencil tests identified significant decrements in footballers compared with runners and swimmers for executive functions, attention, including short-term memory (Digit Span Forward and Backwards and Trail Making Test B) and long-term memory. Matser et al. (1999) identified within the soccer group, an effect of the number of soccer related concussions sustained on attention, long-term memory and visuo-spatial ability. Taken together, their findings point to the number of concussions suffered being a major determinant of the neuropsychological impairment observed and the number of cognitive symptoms reported. The limitations in this research however, are that the concussive and sub-concussive effects were confounded with respect to the decrements, as these researchers set out to examine the effects of heading. Additionally, it appears that deficits observed in soccer players neuropsychological test performance are most likely attributable to concussive effects rather than to cumulative sub-concussive effects caused by heading. This concords with research by Kirkendall and Garrett (2001) and Kirkendall, Jordan and Garrett (2001), due to associated areas of heading where damage to the frontal and anterior temporal lobes occurs thus resulting in executive functioning and short and long-term memory impairment (Rutherford et al., 2003). Tysvaer (1992) concurred with Matser et al. (1999) that deficits in attention after MTBI were present, and reported that 30% of a sample of former Norwegian soccer players reported permanent chronic post-concussive problems including concentration and memory problems.

Criticism exists strongly against the studies carried out by Matser et al. (1999) on soccer players due to the inadequate repeated use of the control groups across studies, the use of unreliable subjective methods of estimating heading frequency and the confounding variables associated with not controlling the effects of one or more concussions (Rutherford et al., 2003). Improvements in methodology and data analysis are clearly necessary in order to separate the effects of heading frequency and concussions, where it is noted, that these effects are much less than has been found in rugby groups.

*American football*

One of the earliest studies on chronic effects of concussion showed that by one year post-injury most patients with MTBI recover fully (Barth et al., 1989). Criticisms of these early studies were that normative date was not yet available and previous head injuries were not taken into account, thereby confounding findings. The underlying factor is that there exists a subset of patients with a poor outcome, with chronic effects due to the effects of concussion (Collins, Grindell et al., 1999). Lovell et al. (1999), in investigating the importance of the loss of consciousness in predicting neuropsychological test performance in American football athletes with MTBI focused only on the acute symptoms due to the often rapid resolution of symptoms after a single concussive injury. The traditional test battery used was aimed at evaluating information processing, attentional processes and visual scanning (inclusive of verbal memory visual-motor coordination and speech fluency) and included the Trail Making Tests A and B and Digit Span tests. It is noteworthy that all groups demonstrated mildly decreased performance on formal tests of processing speed, memory and attentional processing. These findings concord with research carried out by Iverson, Lovell and Smith (2000), again on the acute effects of concussion, using the same test battery. These authors however allude to the fact that the greatest variability in past research findings is from participants who are ‘three months’ post injury (p. 644).

Collins, Grindell et al. (1999) indicate that neuropsychological assessment is a useful indicator of cognitive functioning and add that a history of repetitive MTBI is associated with reduced cognitive performance. Additionally they report that little research examines the long-term chronic morbidity with concussion, even though data shows that a “prior history of head injury increases the risk for sustaining subsequent MTBI” (p. 964). Their results using traditional test measures indicated that prior history is significantly and independently associated with long-term deficits in the domain of executive functioning (Trail Making Test B) and speed of information processing. Of concern was that 20% of their sample experienced multiple concussions. This clearly has implications for return-to-play recommendations, where concussion resolution should be ensured before return-to-play can be attempted. Grindel et al. (2001) stress the importance of evaluating multiple aspects of cognitive function, as neglecting one may lead to an athlete returning to play prematurely and hence result in deleterious chronic affects. Additionally, premature return-to-play is also complicated by the athlete's self report, which is often made conservatively (Field, Collins, Lovell & Maroon, 2003) and hence often results in the cumulative effect of concussive and sub-concussive events.

The first study to report a cumulative effect of concussion in high school athletes (American football, soccer and basketball players), suggested that a more severe on field presentation of concussion markers is evidenced in high school athletes with a pronounced history (cumulative effect) of concussion (Collins, Field et al., 2002). They found using computer-based assessment procedures (ImPACT), that athletes with three or more prior concussions were more likely to experience on-field positive LOC, anterograde amnesia and confusion after a subsequent concussion. It also revealed that athletes with a history of three concussions were 9.3 times more likely than athletes with no history of concussion to demonstrate three to four abnormal on-field markers of concussion severity. These findings suggest a lowered concussion threshold in athletes who sustained repeated concussions and were therefore more vulnerable to future concussions (Collins, Field et al., 2002; Collins, Grindell et al., 1999; Echemendia et al., 2001). The effect of this research has implications for long-term outcome and hence for the chronic effects of repetitive MTBI.

Iverson, Gaetz, Lovell and Collins (2004a) reported similar findings using ImPACT, with a carefully matched cohort of athletes (high school and collegiate) who sustained three or more concussions at baseline. They reported a greater number of post-concussive symptoms with the concussed group than those who had never sustained a concussion. Additionally, variables such as memory, attention and concentration problems were more highly noted by those with repetitive MTBI. These two studies provided provocative evidence for cumulative lingering effects of repetitive MTBI, and appear to be more susceptible to sustaining injuries of greater severity in the future and for chronic deleterious effects (Iverson, Lovell & Collins, 2003).

Field et al. (2003) in evaluating the role age plays in neurocognitive recovery from sports related concussion in high school and Collegiate (university level) athletes, suggested that high school athletes may be at a greater risk for long-term effects due to the fact that a diffuse and more prolonged swelling can occur in children relative to adults and this puts them at greater risk for secondary intracranial hypertension and ischemia, such as occurs in second impact syndrome. This prolonged swelling may lead to a delayed neurocognitive recovery period and make the adolescent more susceptible to permanent chronic cognitive deficits. Limitations in this study were that sex, position and sport played, were not addressed, along with its reliance on self-report measures where the belief that to be successful one must 'play through' injury and hence self-report symptomology is not always reliable due to it being made in a conservative manner (p. 553).

Guskiewicz et al. (2003) in investigating the cumulative effects associated with repetitive MTBI found that players with a history of previous concussions were more likely to have future concussive injuries than those with no history, and that one in fifteen athletes with concussion may have additional concussions in the same playing season. Additionally, these previous concussions may be associated with slower recovery of cognitive function. Their research was limited to American football players who experienced concussions graded according to the Cantu Evidence-Based grading scale across three colleague football seasons. Their objective was to estimate the incidence of concussion and time to recovery after concussion and therefore never focussed on what actual cognitive functions were slow to recover. What is of significance however is that their research indicates that athletes with a high cumulative or repetitive history should be more informed about the increased risk of concussions when continuing to play, the effect this may have on cognitive functioning and the return-to-play decision making process.

*Rugby Union*

There appears to be very limited published research on rugby union, although the available research has provided a particular focus on chronic effects, where two prior studies were noted. One study exists which has investigated the effects of MTBI in rugby by Shuttleworth-Jordan, Balarin, and Puchert (1993), and at the university level, using traditional paper and pencil test measures. The neuropsychological assessment included tests of verbal new learning ability (digit supraspan), immediate auditory span (digit span forwards), speed of information processing and working memory (Trail Making Tests parts A and B and Digit Span backwards), and hand motor dexterity (Denckla finger tapping and Purdue Pegboard tests). The investigation involved two levels of analysis (i) an analysis of pre- and post-season differences between concussed and non-concussed players against matched controls, and (ii) an analysis of test differences between rugby players with a reported mild head injury sustained during the season and matched controls at pre-season, five days, one month, two months and three months post season.

The pre-season comparison of non-concussed players and matched controls in this early study (Shuttleworth-Jordan et al., 1993) indicated the presence in the rugby cohort of a pattern of impairment typically associated with diffuse brain injury. Deficits included working memory, verbal new learning ability and hand motor dexterity. The rugby cohort also showed less capacity than the controls for practice effects between the pre- and post-season testing, also consistent with diffuse brain damage. It was then argued that this phenomenon was likely to be the result of concussions sustained in previous rugby seasons, or unreported concussions during the season of assessment, or a combination of both. Perusal of their results suggests that forwards and backs were not significantly different in terms of decrements on the cognitive tests. This study (Shuttleworth-Jordan et al., 1993) although overcoming some of the limitations of previous studies on MTBI by examining the acute recovery curve up to three months as well as by examining the chronic effects was limited in its small sample size and test battery used, even though the tests were chosen on the basis of tests sensitive to the presence of diffuse brain damage. Additionally, further limitations with respect to methodology were that the control comparisons with the rugby pre- and post-season cohort did not employ a repeated measures design. A random selection of controls and rugby players were chosen for the post-season assessment of the non-concussed rugby group. Also, age and education were not matched statistically, with age and education being only matched by limiting the sample to university students in the age range of 18 – 25 years. Nevertheless, the study provides consistent evidence that show the rugby groups to have chronic decrements on functions which are known to be sensitive to the diffuse brain damage which classically accompanies a closed head injury.

A second study was conducted on school and professional level players using traditional measures involving paper and pencil instruments at the pre-season interval (Shuttleworth-Edwards, Border, Reid & Radloff, 2004). In this research, results for professional rugby players consistently revealed significant cognitive deficits on testing across several neurocognitive modalities relative to controls. These included processing speed (TMTB), verbal (Digit Span-Backwards) and visual memory deficits, supported by a substantially higher percentage of reported memory problems on the post-concussive symptom questionnaire for rugby players relative to controls. The research conducted amongst top-level schoolboy rugby players indicated less robust evidence of cognitive deficits, with delayed verbal recall being the only function implicated on one school study, and processing speed the only function compromised on the other school study. At the professional level, forwards demonstrated greater cognitive deficit than backs whereas there was little evidence for this at the high school level of play, where positional stances are less entrenched than at older more professional levels of play. Limitations of these prior rugby studies were (i) the sample sizes were relatively small, and (ii) only traditional paper and pencil test measures were used.

*Brain Reserve Capacity*

Taken together, all of the above cited studies on the contact sports implicate deleterious consequences of concussive and repetitive MTBI which result in cognitive deficit, both in the acute but also permanent (chronic) domains. Studies have suggested that factors such as cognitive reserve and possible genetic influences may be related to increased symptom presentation after concussion. In this research, the theory of brain reserve capacity (BRC) formulated by Satz (1993) provides a useful theoretical framework for understanding the cumulative effects of repetitive MTBI. In terms of this theory, the amount of functional brain tissue (BRC), which represents physiological brain advantages or disadvantages, and two key psychosocial factors, i.e. general intelligence and educational level, represent indirect measures of BRC. Satz poses that the greater the BRC, the less likelihood there is of an individual exhibiting symptoms of neurological impairment as a higher BRC is likely to act as a protective factor, decreasing the risk of functional impairment. The lower the BRC the more vulnerable an individual will be to showing symptoms of neurological impairment as the threshold (critical amount of brain tissue at which normal functioning can be sustained) will be lower. In terms of the theory, insidious reduction in BRC due to cumulative neurological pathology (such as repetitive MTBI) is likely to increase an individual’s vulnerability to functional impairment (Satz, 1993). A single MTBI in a previously high functioning individual may not be significant enough to push an individual below the cognitive threshold, to reveal cognitive decline. But, an excess of two (as is common in rugby due to the nature of play) might serve to push an individual below the threshold, despite their previous high level of functioning, to reveal cognitive deficits.

### 1.12 Rationale for the present research study

Arising out of the above literature review it is evident that there is abundant support for the deleterious consequences of multiple concussions and sub-concussive episodes on cognition. Studies that focus on persistent effects amongst sports populations are limited relative to concussion on acute effects. Generally, on rugby union there is a paucity of studies, albeit there are two studies that have targeted chronic effects (Shuttleworth-Jordan et al. 1993; Shuttleworth-Edwards et al., 2004), but these used only paper and pencil tests and small samples which were not tightly controlled for age and education at the university level study. Moreover, there was no control for IQ. Thus, for the purposes of the present study it was decided to target a university population using the computer-based ImPACT 3.0 programme in conjunction with the Trail Making Tests (Parts A and B) and Digit Span (Forwards and Backwards) to determine (i) whether there is evidence for the presence of chronic cognitive effects of repetitive MTBI (cumulative concussions and sub-concussive episodes) in this population of university rugby players, with a prior history of playing rugby for a number of years (high school into university), (ii) whether there is evidence for an overlay of acute or chronic effects due to participation in rugby at the university level due to an eight month season, and (iii) whether the sensitivity of the ImPACT neurocognitive composite scores are as sensitive to cognitive decrements relative to the well researched traditional paper and pencil tests of the Trail Making Test (parts A and B) and Digit Span (forwards and backwards).

It was hypothesised that rugby players would be more likely to show cognitive impairment at the pre- and post-season intervals, due to the cumulative effects and a combination of this as a result of insults obtained during the season, than the non-contact sport controls. Additionally, the rugby forwards versus backs in acute and chronic conditions were also investigated to determine if either group would show significant cognitive impairment when compared with one another. Prior research (Shuttleworth-Jordan et al., 1993) together with personal information with head coaches who indicated that positional play is less entrenched at the university level, led to the hypothesis that with this cohort no significant differences would be noted between the forwards and backs. Furthermore, based also on the research outlined by Shuttleworth-Jordan et al. (1993), it was hypothesised that the rugby group would show less capacity than the controls for practice effects between the pre- and post-season intervals, implicating diffuse brain damage effects due to the multiple concussive episodes within the rugby group

# 2. METHODOLOGY

## 2.1 Participants

Critical issues pertaining to this research were passed through the Rhodes University Psychology Department Research Projects Review Committee and permission was granted from the Rhodes University Sports Department to conduct this study. All participants were drawn from Rhodes University's top two Rugby Union team players. The non-contact sports control group consisted of top team members from the University's cricket and swimming teams, sports which are not characterised by multiple concussions due to collisions, such as occur in Rugby Union. The total sample included 48 volunteer participants at the pre-season and 45 volunteer participants at the post season in that three volunteers dropped out between the two seasons due to sampling attrition (in the form of subjects who did not return for testing because of poor cooperation).

*Exclusion of participants*

Exclusion criteria were; any neurological or psychiatric disorder, substance abuse problem, present medication and any athlete with previous moderate to severe head injuries, or a concussion (MTBI) within the season. These exclusions were monitored with the aid of Section A (Background Information) of the Pre-season questionnaire (see Appendix B) and the demographics section of the ImPACT programme. No participants were excluded on these grounds, however one participant was excluded due to his being concussed during the eight-month season. He was diagnosed by a doctor, as having a Grade 2 concussion according to the American Academy of Neurology guidelines. Additionally, participants were monitored with regard to fatigue, poor motivation, transient effects of too little sleep or 'partying', as well as for any traumatic events, that may have interfered with the pre- and post testing sessions. The monitoring of these test-taking exclusions were based on (i) questions from Section B (Current Symptoms and Conditions) of the pre-season questionnaire (see Appendix B), which required participants to answer questions with regard to hours of sleep, current medications and average alcohol on a daily and weekly basis, and (ii) information from the last section of the ImPACT programme that required the participant to list any problems they may have been experiencing at the time of testing. No participants were excluded on the basis of information provided in respect of such test-taking factors.

*Rugby and Controls*

The rugby and control groups were compared for age, education and estimated IQ to establish between-group homogeneity in respect of these variables. Years of education were calculated according to the number of years it usually takes to achieve the education (i.e. not the actual number of years taken to arrive at that level). Additionally, only the number of completed years was counted (i.e. if a participant was in the first year of university, his number of years of education would be 12, due to his attainment of Grade 12). Similarly, a second and third year student would have 13 and 14 years of education respectively. A three-year bachelors degree was noted as 15 years; an honours degree as 16 years and a masters degree as 17 years. With respect to age, particpants' ages were taken at the time of pre-season baseline testing.

On comparisons, significant differences were noted for age and education, with the rugby group having lower years of education than the controls [Age - Rugby M = 19.93 and Control M = 23.39, ($p$ = .002); Education - Rugby M = 19.93 and Control M = 23.39, ($p$ = .003)]. It was considered that this age difference would be unlikely to contribute to any significant effect on cognitive testing, where perusal of the WAIS-III standardisation (1997) in respect of all the subtests indicates a high degree of overlap between the 18-19 and 20-24 year old categories (the age categories that pertain to all participants in the present study). That is, conversion of the same raw score for any particular subtest across these two age groups yields hardly any difference (if any) in scaled scores. Additionally, it was considered that the educational difference was likely to be of no significance in terms of possible influences on cognitive test outcomes in that the two groups were well matched for estimated IQ ($p$ = .254).

However, to further ensure fine control for age and education, the two cohorts (Rugby and Controls) were further matched for age and education by removing (i) all the post graduates from the controls (masters and PhD students) as they were absent in the rugby group, and (ii) first year university students from the rugby group were removed as the control group lacked first year students. The total reduced sample included 48 volunteer participants at the pre-season (30 rugby and 18 controls) and 45 volunteer participants at the post-season (27 rugby and 18 controls). The result of this was that the groups became well matched, with no significant differences noted between any of the variables of age, education and estimated IQ [Education - Rugby M = 13.65 and Controls M = 13.64, ($p$ = .966); Age - Rugby M = 20.25 and Control M = 21.27 ($p$ = .090)] and estimated IQ ($p$ = .500 and $p$ = .821). This more homogenous sample in respect of age and education is then referred to as the reduced sample throughout this study and the initial sample as the large sample. Furthermore, descriptively no differences were noted on a history of special education or diagnosis of learning difficulty (see Table 5). Additionally, there was a significant difference on both sets of results between the rugby group and control group with regard to the number of concussions sustained by rugby players reporting more concussions than controls. This was an expected difference in light of the assumption of the study that rugby players would be at greater risk than non-contact controls for concussive head injuries [(Large sample, pre- and post-season; $p$ = .001 and $p$ = .001 respectively)(Reduced sample, Pre and post-season; $p$ = .003 and $p$ = .010 respectively)].

In sum, the following sample groups were used:

| | | |
|---|---|---|
| 1) | Independent large sample: | Rugby (n=30) and Controls (n=18) |
| | Independent reduced sample: | Rugby (n= 20) and Controls (n=11) |
| | Independent large sample: | Rugby forwards (n=14) and Rugby backs (n=16) |
| | Independent reduced sample: | Rugby forwards (n=9) and Rugby backs (n=11) |
| 2) | Dependent large sample: | Rugby pre-season (n=27) |
| | | Rugby post-season (n=27) |
| | Dependent reduced sample: | Rugby pre-season (n=18) |
| | | Rugby post-season (n-18) |
| 3) | Dependent large sample: | Controls pre-season (n=18) |
| | | Controls post-season (n=18) |
| | Dependent reduced sample: | Controls pre-season (n=11) |
| | | Controls post-season (n=11) |
| 4) | Dependent large sample: | Rugby forwards pre-season (n=13) |
| | | Rugby forwards post-season forwards (n=13) |
| | Dependent reduced sample: | Rugby forwards pre-season (n=8) |
| | | Rugby forwards pre-season (n=8) |
| 5) | Dependent large sample: | Rugby backs pre-season (n=13) |
| | | Rugby backs post-season (n=13) |
| | Dependent reduced sample: | Rugby backs pre-season (n=9) |
| | | Rugby backs post-season (n=9) |

Between group analyses of demographic data at the pre-season and post-season intervals appears in tables 1 to 5 that follow.

Table 1

Demographic data of Rugby versus Controls (Large Sample)

| Pre-season | Rugby (n = 30) Mean (SD) | Control (n = 18) Mean (SD) | *t-value* | *p-value* |
|---|---|---|---|---|
| Age | 19.93 (1.46) | 23.39 (3.87) | -4.421 | .002** |
| Education | 13.27 (1.08) | 14.78 (1.77) | -3.686 | .003** |
| Estimated IQ¹ | 10.90 (2.11) | 10.19 (1.93) | 1.150 | .254 |
| No. of Concussions | 1.60 (1.45) | 0.50 (0.51) | 3.087 | .001†† |
| **Post-season** | **Rugby (n = 27) Mean (SD)** | **Control (n = 18) Mean (SD)** | ***t-value*** | ***p-value*** |
| Age | 19.85 (1.46) | 23.39 (3.87) | -3.708 | .001** |
| Education | 13.22 (1.09) | 14.78 (1.77) | -3.337 | .003** |
| Estimated IQ¹ | 10.65 (1.74) | 10.19 (1.93) | 0.819 | .417 |
| No. of Concussions | 1.56 (1.50) | 0.50 (0.51) | 3.367 | .001†† |

*Note.* ¹Control for estimated IQ established on the average of the Picture Completion and Vocabulary Scaled Scores.
**$p < .01$, two-tailed. ††$p < .01$, one-tailed

Table 2

Demographic data of Rugby versus Controls (Reduced Sample)

| Pre-season | Rugby (n = 20) Mean (SD) | Control (n = 11) Mean (SD) | *t-value* | *p-value* |
|---|---|---|---|---|
| Age | 20.25 (1.33) | 21.27 (1.90) | -1.754 | .090 |
| Education | 13.65 (0.88) | 13.64 (0.80) | 0.043 | .966 |
| Estimated IQ¹ | 10.85 (2.40) | 10.27 (1.94) | 0.684 | .500 |
| No. of Concussions | 1.85 (1.57) | 0.73 (0.47) | 2.307 | .003†† |
| **Post-season** | **Rugby (n = 17) Mean (SD)** | **Control (n = 11) Mean (SD)** | ***t-value*** | ***p-value*** |
| Age | 20.18 (1.33) | 21.27 (1.90) | -1.797 | .084 |
| Education | 13.65 (0.86) | 13.64 (0.81) | 0.033 | .974 |
| Estimated IQ¹ | 10.44 (1.89) | 10.27 (1.94) | 0.228 | .821 |
| No. of Concussions | 1.82 (1.67) | 0.73 (0.47) | 2.115 | .010† |

*Note.* ¹Control for estimated IQ established on the average of the Picture Completion and Vocabulary Scaled Scores.
†$p < .05$, one-tailed. ††$p < .01$, one-tailed

Table 3

Demographic data of Rugby Forwards versus Rugby Backs (Large Sample)

| Pre-season | Forwards (n = 14) Mean (SD) | Backs (n = 16) Mean (SD) | *t-value* | *p-value* |
|---|---|---|---|---|
| Age | 20.43 (1.51) | 19.50 (1.32) | 1.803 | .082 |
| Education | 14.07 (1.50) | 13.00 (0.97) | -3.686 | .025* |
| Estimated IQ[1] | 11.39 (2.16) | 10.47 (2.04) | 1.150 | .238 |
| No. of Concussions | 1.29 (1.33) | 1.88 (1.54) | -1.113 | .275 |
| **Post-season** | **Forwards (n = 13) Mean (SD)** | **Backs (n = 14) Mean (SD)** | ***t-value*** | ***p-value*** |
| Age | 20.54 (1.51) | 19.21 (1.12) | 2.604 | .015* |
| Education | 13.62 (1.19) | 12.86 (0.86) | 1.902 | .069 |
| Estimated IQ[1] | 11.04 (1.77) | 10.23 (1.70) | 1.128 | .270 |
| No. of Concussions | 1.31 (1.38) | 1.79 (1.63) | -0.821 | .419 |

*Note.* [1]Control for estimated IQ established on the average of the Picture Completion and Vocabulary Scaled Scores.
**p* < .05.

Table 4

Demographic data of Rugby Forwards versus Rugby Backs (Reduced Sample)

| Pre-season | Forwards (n = 9) Mean (SD) | Backs (n = 11) Mean (SD) | *t-value* | *p-value* |
|---|---|---|---|---|
| Age | 20.56 (1.51) | 20.00 (1.18) | 0.924 | .368 |
| Education | 13.89 (0.93) | 13.45 (0.82) | 0.043 | .281 |
| Estimated IQ[1] | 11.28 (2.51) | 10.50 (2.36) | 0.684 | .485 |
| No. of Concussions | 1.33 (1.41) | 2.27 (1.62) | 2.307 | .189 |
| **Post-season** | **Forwards (n = 8) Mean (SD)** | **Backs (n = 9) Mean (SD)** | ***t-value*** | ***p-value*** |
| Age | 20.75 (1.49) | 19.67 (1.00) | 1.781 | .095 |
| Education | 14.00 (0.93) | 13.33 (0.71) | 1.680 | .114 |
| Estimated IQ[1] | 10.69 (1.91) | 10.22 (1.95) | 0.495 | .627 |
| No. of Concussions | 1.38 (1.51) | 2.22 (1.79) | -1.049 | .311 |

*Note.* [1]Control for estimated IQ established on the average of the Picture Completion and Vocabulary Scaled Scores.
**p* < .05.

Table 5

Extended demographic data of participants for large sample and reduced sample.

| Matched Variables | Rugby (large) (n = 30) Total (%) | | Control (large) (n = 18) Total (%) | | Rugby (reduced) (n = 20) Total (%) | | Controls (reduced) (n = 11) Total (%) | |
|---|---|---|---|---|---|---|---|---|
| White | 26 | (86.6) | 17 | (94.0) | 17 | (85.0) | 10 | (90.9) |
| Non-white | 4 | (13.3) | 1 | (5.5) | 3 | (15.0) | 1 | (9.1) |
| English 1st Language | 28 | (93.0) | 17 | (94.0) | 18 | (90.0) | 10 | (90.0) |
| English 2nd Language | 2 | (6.6) | 1 | (5.5) | 2 | (10.0) | 1 | (9.1) |
| Learning Disability | 0 | (0) | 0 | (0) | 0 | (0) | 0 | (0) |
| Remedial Education | 0 | (0) | 0 | (0) | 0 | (0) | 0 | (0) |
| Handedness Right | 25 | (83.0) | 15 | (83.0) | 17 | (85.0) | 10 | (90.9) |
| Handedness left | 5 | (16.6) | 3 | (16.6) | 3 | (15.0) | 1 | (9.9) |
| Occupational Therapy | 0 | (0) | 0 | (0) | 0 | (0) | 0 | (0) |
| Speech therapy | 1 | (3.3) | 1 | (5.5) | 0 | (0) | 0 | (0) |
| ADHD | 0 | (0) | 0 | (0) | 0 | (0) | 0 | (0) |
| Treatment for substance abuse | 0 | (0) | 0 | (0) | 0 | (0) | 0 | (0) |
| Treatment for psychiatric condition | 0 | (0) | 0 | (0) | 0 | (0) | 0 | (0) |

*Participant Consent*

All participants were required to sign a consent form before the assessment began. The consent form consisted of a comprehensive description of the nature of the research and emphasised the importance of concussion management in sport and risk prevention, although the project was voluntary (see Appendix A). It was explained to participants that they could withdraw, but that their withdrawal should be in writing. A withdrawal form was attached to their consent form. The assessment process only commenced once this consent form was received.

## 2.2 Procedures

*Baseline evaluation*

In a group setting, all participating athletes were administered, a preseason baseline evaluation (session one) which was composed of (i) a self report demographics questionnaire and extended concussive symptom checklist, and (ii) Picture Completion and Vocabulary Sub-tests of the Wechsler Adult Intelligence Scale-Third Edition. During the second session participants were administered individually the (i) ImPACT 3.0, (ii) Trail Making Tests A and B, and (iii) Digit Span (Wechsler Adult Intelligence Scale-Third Edition).

*The demographic questionnaire*

The demographic questionnaire (see Appendix B) was completed by all participants and provided important demographic information regarding personal history (age, level of education, first language, learning disability, etc) and sporting history (sport played, position and duration and history of concussion, LOC, presence and length of confusion, anterograde amnesia, retrograde amnesia and treatment by a physician for any associated reason). The demographics questionnaire was designed to identify the individuals who needed to be excluded. Exclusion criteria were; any neurological or psychiatric disorder, substance abuse problem, present medication and any athlete with previous moderate to severe head injuries, or a concussion (MTBI) within the season. No participants were excluded on these grounds, however one participant was excluded due to his being concussed during the eight-month season. He was diagnosed by a doctor, as having a Grade 2 concussion according to the American Academy of Neurology guidelines

*WAIS-III Sub-tests for Picture Completion and Vocabulary*

A control for estimated pre-morbid IQ was calculated using two subtests from the Wechsler Adult Intelligence Scale-Third Edition (WAIS-III): Vocabulary and Picture Completion, as both tests are considered to be relatively unaffected in the presence of diffuse damage and are therefore good indicators of pre-morbid ability (Lezak, et al., 2004). Given that these measures were used to establish estimated IQ equivalence for comparative groups, rather than an estimated IQ per se, the deviation from the standard individual administration (to a group administration) was considered to be legitimate given that all participants were exposed to the identical modified procedures. The Picture Completion subtest has consistently demonstrated resilience to the effects of brain damage and is relatively unaffected by diffuse brain damage and is therefore a good test of previous ability (Lezak et al., 2004). This test consists of 25 drawings, each of which is missing an important part, which the participant must identify. The pictures were presented in numerical order, in a group administration setting and projected onto a screen. The Picture Completion Subtest instructions for this test were taken from the WAIS-III manual (Wechsler, 1997). The participants were asked to write down the missing detail on an answer sheet, which was constructed in a similar fashion to the answer sheet for the WAIS-III (see Appendix C). Participants were given 20 seconds per picture. Scoring was carried out as prescribed in the WAIS-III manual; one point was given for each correct response. Due to the group administration, the discontinue rule after five consecutive scores of zero could not be applied.

The Vocabulary test is recognised as a test for general mental ability (Lezak et al., 2004) and when brain injury is diffuse, it tends to be the least affected of the Wechsler Intelligence subtests (Zillmer, Waechtler & Harris, 1992). Instructions for the Vocabulary Subtest were taken from the WAIS-III manual (Wechsler, 1997). The test consisted of 33 words. Each word was presented to the participants in a group setting and they were required to write down definitions for the words presented (traditional paper and pencil administration). Participants were advised to write down and explain what they “thought the word meant” (p. 69). Due to the administration of this test in a group setting, the discontinue rule could again not be applied. Scoring was carried out as prescribed by the Wais-III manual; 2, 1 or 0 points were awarded depending on the participant’s definition of the word (see Appendix C).

*ImPACT 3.0*

This is a computer-based test used for concussion management, with five composite scores combined to be sensitive to the sequelae of concussion, as previously described under section 1.6 (p.12). All participants underwent the administration of the computerised test battery ImPACT 3.0. This was undertaken individually on a stand-alone-computer in a small testing room so that no distractions were present. The test took about 25 minutes, whereupon completion, the scores were stored and a report was printed for each participant at both the base-line pre-season testing session and the post-season testing session. These scores were then arranged on a spread sheet to allow for statistical analyses. A comprehensive description of this test was given in section 1.6.

*Trail Making Test A and B*

The Trail Making Test is a test considered to be sensitive to the effects of diffuse brain damage, as described under section 1.9 (p. 16). This test consists of two parts, A and B. Part A consists of a series of numbers within circles on a sheet of paper. Standard test administration was carried out as described in Lezak et al. (2004). Participants were instructed to join the numbers in the correct sequence “as fast as you can” without lifting their pencils from the page (p. 371). The participants first completed a mini practice trial before proceeding onto the test. If the participants made a mistake, it was immediately pointed out to them and they were required to correct it immediately. The score was the time taken to complete the trial. Part B is similar in format and administration to trial A, except that the participants were required to join alternating numbers and letters in the correct response (see Appendix C).

*Digit Span (Forwards and backwards)*

The Digit Span test is also a test considered to be sensitive to the effects of diffuse brain damage, as described under section 1.10 (p. 16). The Digit Span from the WAIS-III was administered as described in the WAIS-III manual. Separate scores for digits forwards and backwards were calculated rather than a composite score, as prior research has indicated that scores on Digit Span are particularly sensitive to diffuse brain damage, which might be expected after a closed head injury (Lezak, 1995). *Forwards*-Participants were asked to repeat in the correct order; a sequence of numbers after the researcher had finished reading them. Each trial consisted of a pair of sequences consisting of the same amount of numbers. If a participant was able to repeat one sequence of a trial, the researcher continued with the next trial, which consisted of an extra number. The test was discontinued after two sequences of a trial were failed. The score was the longest sequence of numbers correctly repeated, as prescribed by the Wechsler Adult Intelligence Scale-Third Edition manual (Wechsler, 1997). *Backwards*-The instructions differ from digits forward in that the participant was instructed to repeat in the reverse order, the sequence of numbers, which the researcher read out (see Appendix C).

*Post-season Evaluation*

At the end of the Rugby Union season, all participating athletes were administered a post-season evaluation, which entailed replicating the test battery that was administered individually at pre-season, including (i) ImPACT 3.0, (ii) Trail Making Tests A and B, and (iii) Digit Span (WAIS-III).

*Scoring*

All protocols were scored by the three intern clinical psychologists involved in the research. Instructions for the scoring of the protocols were standardised according to the instructions from the Wechsler Adult Intelligence Scale-Third Edition manual to minimise differences between test administrators. The scoring instructions were used in consultation with each intern clinical psychologist and protocols were marked and remarked by all three intern clinical psychologists. Consensus amongst the three intern clinical psychologists was achieved in cases of scoring uncertainty.

## 2.3 Data processing

To investigate pre- and post-season concussive effects, with regard to cognitive deficits, subgroup comparisons via t-test analyses were conducted between rugby and non-contact sports controls and for forwards versus backs, for all neurocognitive data at the pre- and post-season intervals (ImPACT 3.0, Trail Making Tests A and B, and Digit Span). A directional hypothesis was assumed for the comparison between rugby versus controls permitting the use of a one-tailed test in that it was expected that rugby players would perform worse than controls due to the nature of play in this contact sport (the use of a one-tailed significant value permits division of the *p* value by two). In respect of dependent comparisons to investigate the pre- and post-concussive effects within the forwards versus backs and controls pre- and post season, it was uncertain whether (i) improvements on cognitive testing would be noted, (ii) whether poorer performance would be seen due to previous effects of having sustained concussions or because of the long term effects of concussion, and (iii) if results would remain stable. No directional hypothesis could be assumed; therefore two-tailed significant values were used, (i.e. the obtained *p* values were retained and not divided by two).

The comparative results for the neuropsychological assessment between the participants, including mean scores, standard deviations, t-statistics and significant differences (*p* values) are represented in the tables that follow. In all the tables ‘significance’ is represented by: $* p < .05$, two-tailed. $** p < .01$, two-tailed. $^{\dagger} p < .05$, one-tailed. $^{\dagger\dagger} p < .01$, one-tailed. In each case the following comparisons were made:

Table 6

List of t-test comparisons

| COMPARISON | NEUROPSYCHOLOGICAL ASSESSMENT | |
|---|---|---|
| Demographic data | Tables 1 and 2 | Page 27 |
| Demographic data | Tables 3 and 4 | Page 28 |
| Extended demographic data | Table 5 | Page29 |
| Rugby versus controls: across all tests | Tables 7 and 8 | Page 36/7 |
| Rugby forwards versus backs: across all tests | Tables 9 and 10 | Page 38/9 |
| Rugby pre-season versus rugby post-season: across all tests | Tables 11 and 12 | Page 40 |
| Controls pre-season versus controls post-season: across all tests | Tables 13 and 14 | Page 41 |
| Forwards pre-season versus forwards post-season: across all tests | Tables 15 and 16 | Page 42 |
| Backs pre-season versus backs post-season: across all tests | Tables 17 and 18 | Page 43 |

# 3. RESULTS

## 3.1 Rugby versus controls: Independent t-test comparisons across all tests

It is important to note that whilst interpreting the composite scores on ImPACT, better scores are higher scores with the exception of Impulse Control, where a better score is a lower score. With regard to descriptive trends on the raw data, directional trends were used to illustrate better or worse performance amongst a group of scores for either rugby players or controls. Finally, 'significance' is represented by: * $p < .05$, two-tailed. ** $p < .01$, two-tailed. $^{\dagger} p < .05$, one-tailed. $^{\dagger\dagger} p < .01$, one-tailed.

The statistical analyses revealed significant effects for independent t-test comparisons of the large rugby group versus the control group in the direction of poorer performance for the rugby group (see Table 7). With respect to specific composite scores of ImPACT 3.0, it was found that the rugby group performed significantly more poorly than controls in post-season verbal memory ($p = .045$), post-season visual memory ($p = .0440$), pre- and post-season visuo-motor speed ($p = .028$ and $p = .020$ respectively), pre-season reaction time ($p = .020$), and post-season impulse control ($p = .020$). Also evident when perusing the traditional measures of Trail Making Tests, significant effects for Post-Trail Making Tests A and B ($p = 0.11$ and $p = .018$ respectively) were also found in the direction of poorer performance for the rugby group. Furthermore, post-season reaction time and post-season digits backwards indicated values approaching significance ($p = .057$ and $p = .065$ respectively) where the rugby group performed worse than the controls. Additionally, inspection of the results of rugby versus controls (Table 7) reflects a general trend of better performance on the tests for the control group (seventeen out of eighteen), with the exception of pre-digits backwards.

Statistical analyses on the reduced sample (see Table 8) revealed significant effects in respect of ImPACT 3.0 composites on the Pre-verbal memory ($p = .047$) and Post-Impulse Control ($p = .033$) in the direction of poorer performance for the rugby union players. Traditional measures revealed significant effects for the Post-Trail Making Tests A and B ($p = 0.46$ and $p = .030$) respectively, in the direction of poorer performance for the rugby players. Although there are smaller numbers in the reduced sample, a similar pattern emerged with significant effects, which support the findings of the large sample, where scores reflect a general, trend of better performance on the test for the control group (fifteen out of eighteen tests), with the exception of pre- and post-reaction time and pre-digits backwards.

Table 7

Independent t-test for comparisons of the total Rugby group versus Controls (large sample) including scores for ImPACT 3.0, Trail Making Test A and B and Digit Span.

| | Rugby (n = 30) Mean (SD) | | Control (n = 18) Mean (SD) | | *t-value* | *p-value* |
|---|---|---|---|---|---|---|
| Pre-verbal Memory | 88.90 | (8.56) | 91.44 | (5.85) | -1.110 | .136 |
| Post-Verbal Memory | 89.00 | (8.25) | 93.22 | (7.53) | -1.740 | .045† |
| Pre-visual memory | 76.40 | (15.08) | 80.22 | (12.50) | -0.904 | .186 |
| Post-visual memory | 77.26 | (14.35) | 84.28 | (11.23) | -1.746 | .044† |
| Pre-VMS | 35.63 | (6.47) | 39.36 | (6.26) | -1.959 | .028† |
| Post-VMS | 35.61 | (7.84) | 40.26 | (6.20) | -2.110 | .020† |
| Pre-Reaction Time | 0.58 | (0.05) | 0.55 | (0.05) | 2.120 | .020† |
| Post-Reaction Time | 0.57 | (0.06) | 0.54 | (0.05) | 1.610 | .057 |
| Pre-Impulse Control | 6.60 | (6.40) | 5.56 | (2.98) | 0.650 | .224 |
| Post-Impulse Control | 10.15 | (10.32) | 4.72 | (3.74) | 2.130 | .020† |
| Pre-TMT A | 25.56 | (7.19) | 22.53 | (5.81) | 1.510 | .069 |
| Post-TMT A | 24.15 | (7.68) | 19.46 | (3.78) | 2.390 | .011† |
| Pre-TMT B | 58.72 | (17.39) | 52.01 | (12.58) | 1.420 | .081 |
| Post-TMT B | 53.26 | (20.05) | 43.70 | (8.63) | 1.903 | .018† |
| Pre-Digits Forward | 11.23 | (1.87) | 11.83 | (1.43) | -1.171 | .124 |
| Post-Digits Forward | 10.85 | (1.83) | 10.94 | (1.96) | -0.162 | .436 |
| Pre-Digits Backwards | 7.47 | (2.42) | 7.22 | (1.83) | 0.369 | .357 |
| Post-Digits Backwards | 7.30 | (2.61) | 8.44 | (2.15) | -1.540 | .065 |

*Note.* † $p < .05$, one-tailed.

Table 8

Independent t-test for comparisons of the total Rugby group versus Controls (reduced sample) including scores for ImPACT 3.0, Trail Making Test A and B and Digit Span.

| | Rugby (n = 20) Mean (SD) | | Control (n = 11) Mean (SD) | | *t-value* | *p-value* |
|---|---|---|---|---|---|---|
| Pre-verbal Memory | 88.10 | (9.96) | 92.45 | (4.32) | -1.425 | .047† |
| Post-Verbal Memory | 89.18 | (7.80) | 92.36 | (7.24) | -1.085 | .144 |
| Pre-visual memory | 74.75 | (14.95) | 81.45 | (12.54) | -1.261 | .109 |
| Post-visual memory | 75.35 | (15.05) | 82.55 | (11.82) | -1.337 | .097 |
| Pre-VMS | 37.14 | (6.51) | 40.15 | (6.74) | -1.217 | .117 |
| Post-VMS | 36.66 | (7.56) | 40.11 | (6.96) | -1.215 | .118 |
| Pre-Reaction Time | 0.58 | (0.05) | 0.56 | (0.05) | 1.169 | .126 |
| Post-Reaction Time | 0.56 | (0.06) | 0.54 | (0.05) | 0.765 | .226 |
| Pre-Impulse Control | 6.45 | (5.11) | 5.45 | (2.12) | 0.614 | .227 |
| Post-Impulse Control | 9.65 | (5.45) | 5.91 | (4.23) | 1.925 | .033† |
| Pre-TMT A | 24.88 | (6.69) | 24.03 | (5.43) | 0.361 | .361 |
| Post-TMT A | 23.49 | (5.68) | 19.98 | (4.25) | 1.750 | .046† |
| Pre-TMT B | 59.70 | (16.93) | 51.89 | (11.00) | 1.373 | .090 |
| Post-TMT B | 50.86 | (13.82) | 42.97 | (7.28) | 1.738 | .030† |
| Pre-Digits Forward | 11.15 | (2.01) | 11.91 | (1.64) | -1.071 | .147 |
| Post-Digits Forward | 10.94 | (1.89) | 11.09 | (1.81) | -0.208 | .419 |
| Pre-Digits Backwards | 7.75 | (2.45) | 7.36 | (1.36) | 0.482 | .317 |
| Post-Digits Backwards | 8.18 | (2.68) | 8.73 | (1.74) | -0.603 | .276 |

*Note.* † $p < .05$, one-tailed.

### 3.2 Rugby forwards versus backs: Independent t-tests across all comparisons

Statistical analyses of the rugby forwards versus backs (large sample) across all tests (see Table 9) revealed no significant findings except for one isolated significant effect on pre-season digits forward ($p$ = .019) where backs indicated poorer performance than forwards. An analysis of trends on the large sample revealed a tendency for forwards to perform better than backs (fourteen out of eighteen tests), backs performed better on three tests and the rugby groups obtained the same score on one test. On the reduced sample (see Table 10), statistical analyses revealed no significant findings except for the isolated significant effect on pre-season digits forward ($p$ = .005), as was found in the large sample, where backs indicated poorer performance than forwards. An analysis of trends revealed that forwards performed better on ten tests, backs performed better on seven tests and the rugby groups obtained the same score on one test. Hence, overall results obtained on the reduced sample are broadly consistent with the results obtained on the large sample, reflecting no significant differences, with the exception of an isolated effect for pre-digits forwards where the rugby backs performed worse than the forwards. Albeit not as pronounced as for the large sample, the analyses of trends on the reduced sample revealed a stronger tendency for forwards to perform better than backs.

Table 9

Independent t-test for comparisons of Rugby Forwards versus Rugby Backs (large sample) including scores for ImPACT 3.0, Trail Making Test A and B and Digit Span.

| | Rugby Forwards (n = 14) Mean (*SD*) | Rugby Backs (n = 16) Mean (*SD*) | *t-value* | *p-value* |
|---|---|---|---|---|
| Pre-verbal Memory | 89.07 (7.47) | 88.75 (9.66) | 0.101 | .920 |
| Post-Verbal Memory | 87.08 (9.60) | 90.79 (6.62) | -1.176 | .251 |
| Pre-visual memory | 77.50 (15.63) | 75.44 (15.02) | 0.368 | .716 |
| Post-visual memory | 75.00 (15.64) | 79.36 (13.28) | -0.782 | .441 |
| Pre-VMS | 35.88 (6.45) | 35.42 (6.69) | 0.192 | .849 |
| Post-VMS | 36.78 (8.98) | 34.52 (6.76) | 0.742 | .465 |
| Pre-Reaction Time | 0.58 (0.06) | 0.58 (0.04) | -0.221 | .827 |
| Post-Reaction Time | 0.57 (0.06) | 0.56 (0.07) | 0.290 | .774 |
| Pre-Impulse Control | 7.00 (7.18) | 6.25 (5.85) | 0.315 | .755 |
| Post-Impulse Control | 6.46 (4.29) | 13.57 (13.03) | -1.873 | .073 |
| Pre-TMTA | 24.27 (7.32) | 26.70 (7.11) | -0.921 | .365 |
| Post-TMTA | 23.18 (5.23) | 25.04 (9.53) | -0.622 | .539 |
| Pre-TMTB | 55.69 (19.19) | 61.37 (15.79) | -0.888 | .382 |
| Post-TMTB | 49.62 (11.50) | 56.65 (25.62) | -0.907 | .373 |
| Pre-Digits Forward | 12.07 (1.90) | 10.50 (1.55) | 2.495 | .019* |
| Post-Digits Forward | 11.23 (2.01) | 10.50 (1.65) | 1.036 | .310 |
| Pre-Digits Backwards | 7.79 (3.07) | 7.19 (1.72) | 0.670 | .509 |
| Post-Digits Backwards | 8.15 (2.79) | 6.50 (2.25) | 1.702 | .101 |

*Note.* *$p < .05$.

Table 10

Independent t-test for comparisons of Rugby Forwards versus Rugby Backs (reduced sample) including scores for ImPACT 3.0, Trail Making Test A and B and Digit Span.

| | Rugby Forwards (n = 9) Mean (*SD*) | Rugby Backs (n = 11) Mean (*SD*) | *t-value* | *p-value* |
|---|---|---|---|---|
| Pre-verbal Memory | 87.78 (8.35) | 88.36 (10.85) | -0.133 | .896 |
| Post-Verbal Memory | 87.63 (9.41) | 90.56 (6.29) | -0.763 | .457 |
| Pre-visual memory | 74.89 (12.40) | 74.64 (17.36) | 0.037 | .971 |
| Post-visual memory | 73.00 (14.29) | 77.44 (16.25) | -0.595 | .561 |
| Pre-VMS | 37.38 (5.93) | 36.93 (7.24) | 0.151 | .882 |
| Post-VMS | 36.64 (9.63) | 36.68 (5.75) | -0.010 | .992 |
| Pre-Reaction Time | 0.58 (0.04) | 0.58 (0.05) | 0.062 | .951 |
| Post-Reaction Time | 0.57 (0.04) | 0.54 (0.07) | 0.750 | .465 |
| Pre-Impulse Control | 6.67 (4.87) | 6.27 (5.53) | 0.167 | .869 |
| Post-Impulse Control | 7.25 (3.66) | 11.78 (6.08) | -1.830 | .087 |
| Pre-TMTA | 23.87 (5.69) | 25.71 (7.57) | -0.603 | .554 |
| Post-TMTA | 24.31 (5.91) | 22.76 (5.73) | 0.549 | .591 |
| Pre-TMTB | 57.34 (19.18) | 61.62 (15.53) | -0.552 | .588 |
| Post-TMTB | 52.74 (12.30) | 49.19 (15.59) | 0.516 | .613 |
| Pre-Digits Forward | 12.44 (1.88) | 10.09 (1.45) | 3.169 | .005** |
| Post-Digits Forward | 11.63 (2.07) | 10.33 (1.58) | 1.458 | .166 |
| Pre-Digits Backwards | 8.56 (3.05) | 7.09 (1.70) | 1.361 | .190 |
| Post-Digits Backwards | 9.38 (2.50) | 7.11 (2.47) | 1.873 | .081 |

*Note.* *$p < .05$, **$p < .01$.

### 3.3 Rugby pre-season versus rugby post-season: Dependent t-tests across all comparisons

Dependent t-tests for comparisons of rugby pre-season versus rugby post-season, across all tests on the large sample revealed no significant findings (see Table 11). Similarly, scores on the reduced sample (see Table 12) indicated no significant findings, except an isolated significant effect on the ImPACT 3.0 reaction time composite for which an improvement of 0.02 seconds was noted between the pre- and post-seasons ($p$ = .021) (see Table 12). No consistent trends were noted on either the large or reduced sample for pre- or post-season intervals across all comparisons.

Table 11

Dependent t-test for comparisons of Rugby Pre-season versus Rugby Post-season (large sample) including scores for ImPACT 3.0, Trail Making Test A and B and Digit Span.

| Paired Samples | Rugby Pre-season (n = 27) Mean (SD) | Rugby Post-season (n = 27) Mean (SD) | *t-value* | *p-value* |
|---|---|---|---|---|
| Verbal Memory | 88.70 (7.96) | 89.00 (8.25) | -0.170 | .866 |
| Visual memory | 77.70 (14.24) | 77.26 (14.35) | 0.196 | .846 |
| VMS | 36.18 (6.43) | 35.60 (7.84) | 0.387 | .702 |
| Reaction Time | 0.58 (0.05) | 0.57 (0.06) | 1.030 | .313 |
| Impulse Control | 6.56 (6.59) | 10.15 (10.32) | -1.653 | .110 |
| TMTA | 24.86 (7.05) | 24.15 (7.68) | 0.461 | .649 |
| TMTB | 58.72 (17.45) | 53.26 (20.05) | 1.332 | .194 |
| Digits Forward | 11.33 (1.90) | 10.85 (1.80) | 1.496 | .147 |
| Digits Backwards | 7.48 (2.49) | 7.30 (2.61) | 0.370 | .715 |

*Note.* *$p < .05$.

Table 12

Dependent t-test for comparisons of Rugby Pre-season versus Rugby Post-season (reduced sample) including scores for ImPACT 3.0, Trail Making Test A and B and Digit Span.

| Paired Samples | Rugby Pre-Season (n = 18) Mean (SD) | Rugby Post-Season (n = 18) Mean (SD) | *t-value* | *p-value* |
|---|---|---|---|---|
| Verbal Memory | 87.83 (8.59) | 89.56 (7.73) | -1.063 | .303 |
| Visual memory | 77.17 (13.61) | 76.44 (15.32) | 0.244 | .810 |
| VMS | 38.30 (5.95) | 36.98 (7.46) | 0.672 | .511 |
| Reaction Time | 0.58 (0.04) | 0.56 (0.06) | 2.532 | .021* |
| Impulse Control | 7.44 (6.88) | 9.44 (5.36) | -1.151 | .266 |
| TMTA | 23.46 (6.00) | 23.20 (5.65) | 0.141 | .890 |
| TMTB | 59.94 (16.44) | 51.05 (13.43) | 1.812 | .088 |
| Digits Forward | 11.22 (2.10) | 10.89 (1.84) | 0.842 | .412 |
| Digits Backwards | 7.94 (2.53) | 8.17 (2.60) | -0.337 | .740 |

*Note.* *$p < .05$.

**3.4 Controls pre-season vs. controls post-season: Dependent t-tests across all comparisons**

Statistical analyses for controls pre-season versus post-season across all tests (see Table 13), produced significant effects in the large sample on Trail Making Tests A and B ($p$ = .036 and $p$ = .001 respectively) and on Digits Backwards ($p$ = .018), indicating improvements between the pre- and post-seasons. Significant improvements at the post-season relative to the pre-season were also found in the reduced sample (see Table 14) for Trail Making Test B ($p$ = .007) and Digits Backwards ($p$ = .023). Additionally, Trail Making Test A pre-season relative to post-season revealed an improvement shown to be approaching significance ($p$ = .059). Furthermore, it was noted that there was a general trend for improvements at post-season versus pre-season, across the tests in the large sample (seven out of nine improvements).

Table 13

Dependent t-test for comparisons of Controls Pre-season versus Controls Post-season (large sample) including scores for ImPACT 3.0, Trail Making Test A and B and Digit Span.

| Paired Samples | Controls Pre-Season (n = 18) Mean (SD) | | Controls Post-Season (n = 18) Mean (SD) | | *t-value* | *p-value* |
|---|---|---|---|---|---|---|
| Verbal Memory | 91.44 | (5.85) | 93.22 | (7.54) | -0.853 | .406 |
| Visual memory | 80.22 | (12.50) | 84.28 | (11.23) | -1.147 | .267 |
| VMS | 39.37 | (6.26) | 40.26 | (6.20) | -0.925 | .368 |
| Reaction Time | 0.55 | (0.05) | 0.54 | (0.05) | 0.571 | .576 |
| Impulse Control | 5.56 | (2.98) | 4.72 | (3.74) | 0.812 | .428 |
| TMTA | 22.53 | (5.81) | 19.46 | (3.78) | 2.279 | .036* |
| TMTB | 52.00 | (12.58) | 43.70 | (8.63) | 3.820 | .001** |
| Digits Forward | 11.83 | (1.43) | 10.94 | (1.96) | 1.861 | .080 |
| Digits Backwards | 7.22 | (1.83) | 8.44 | (2.15) | -2.610 | .018* |

*Note.* $*p < .05$, $**p < .01$.

Table 14

Dependent t-test for comparisons of Controls Pre-season versus Controls Post-season (reduced sample) including scores for ImPACT 3.0, Trail Making Test A and B and Digit Span.

| Paired Samples | Controls Pre-Season (n = 11) Mean (SD) | | Controls Post-Season (n = 11) Mean (SD) | | *t-value* | *p-value* |
|---|---|---|---|---|---|---|
| Verbal Memory | 92.45 | (4.32) | 92.36 | (7.24) | 0.041 | .968 |
| Visual memory | 81.45 | (12.54) | 82.55 | (11.82) | -0.295 | .774 |
| VMS | 40.15 | (6.74) | 40.11 | (6.96) | 0.036 | .972 |
| Reaction Time | 0.56 | (0.05) | 0.54 | (0.05) | 1.049 | .319 |
| Impulse Control | 5.45 | (2.12) | 5.91 | (4.23) | -0.371 | .718 |
| TMTA | 24.03 | (5.43) | 19.98 | (4.25) | 2.132 | .059 |
| TMTB | 51.89 | (11.00) | 42.97 | (7.28) | 3.381 | .007** |
| Digits Forward | 11.91 | (1.64) | 11.09 | (1.81) | 1.218 | .251 |
| Digits Backwards | 7.36 | (1.36) | 8.73 | (1.74) | -2.677 | .023* |

*Note.* $*p < .05$, $**p < .01$.

### 3.5 Forwards pre-season versus forwards post-season: Dependent t-tests across all comparisons

Dependent t-test comparisons for forwards pre-season versus post-season on both the large and reduced samples revealed no significant findings across any test (see tables 15 and 16 respectively). Additionally, no consistent trends were noted across any of the scores.

Table 15

Dependent t-test for comparisons of Forwards Pre-season versus Forwards Post-season (large sample) including scores for ImPACT 3.0, Trail Making Test A and B and Digit Span.

| Paired Samples | Forwards Pre-Season (n = 13) Mean (SD) | Forwards Post-Season (n = 13) Mean (SD) | *t-value* | *p-value* |
|---|---|---|---|---|
| Verbal Memory | 88.23 (7.05) | 87.08 (9.60) | 0.378 | .712 |
| Visual memory | 77.31 (16.26) | 75.00 (15.64) | 0.571 | .578 |
| VMS | 36.38 (6.42) | 36.78 (8.98) | -0.173 | .865 |
| Reaction Time | 0.58 (0.06) | 0.57 (0.06) | 0.542 | .598 |
| Impulse Control | 6.69 (7.38) | 6.46 (4.29) | 0.127 | .901 |
| TMTA | 24.03 (7.56) | 23.18 (5.23) | 0.450 | .660 |
| TMTB | 56.20 (19.88) | 49.62 (11.50) | 1.175 | .263 |
| Digits Forward | 12.23 (1.88) | 11.23 (2.01) | 1.927 | .078 |
| Digits Backwards | 7.77 (3.19) | 8.15 (2.79) | -0.515 | .616 |

*Note.* $*p < .05$.

Table 16

Dependent t-test for comparisons of Forwards Pre-season versus Forwards Post-season (reduced sample) including scores for ImPACT 3.0, Trail Making Test A and B and Digit Span.

| Paired Samples | Forwards Pre-Season (n = 8) Mean (SD) | Forwards Post-Season (n = 8) Mean (SD) | *t-value* | *p-value* |
|---|---|---|---|---|
| Verbal Memory | 86.25 (7.46) | 87.63 (9.41) | -0.503 | .630 |
| Visual memory | 74.25 (13.10) | 73.00 (14.29) | 0.199 | .848 |
| VMS | 38.39 (5.46) | 36.64 (9.63) | 0.502 | .631 |
| Reaction Time | 0.59 (0.05) | 0.57 (0.04) | 1.340 | .222 |
| Impulse Control | 6.13 (4.91) | 7.25 (3.66) | -1.062 | .324 |
| TMTA | 23.43 (5.92) | 24.31 (5.91) | -0.397 | .703 |
| TMTB | 58.37 (20.24) | 52.74 (12.30) | 0.658 | .531 |
| Digits Forward | 12.75 (1.75) | 11.63 (2.07) | 1.843 | .108 |
| Digits Backwards | 8.63 (3.25) | 9.38 (2.50) | -0.664 | .528 |

*Note.* $*p < .05$.

### 3.6 Backs pre-season versus backs post-season: Dependent t-tests across all comparisons

Dependent t-test comparisons for backs pre-season versus backs post-season across all tests revealed no significant findings nor trends on either sample (see Tables 17 and 18 respectively). However, one isolated significant effect was found on the reduced sample with impulse control ($p$ = .029), in the direction of poorer performance at the post-season.

Table 17

Dependent t-test for comparisons of Backs Pre-season versus Backs Post-season (large sample) including scores for ImPACT 3.0, Trail Making Test A and B and Digit Span.

| Paired Samples | Backs Pre-Season (n = 13) Mean (SD) | Backs Post-Season (n = 13) Mean (SD) | *t-value* | *p-value* |
|---|---|---|---|---|
| Verbal Memory | 89.14 (8.96) | 90.79 (6.62) | -0.886 | .392 |
| Visual memory | 78.07 (12.69) | 79.36 (13.28) | -0.560 | .585 |
| VMS | 36.00 (6.67) | 34.52 (6.76) | 0.748 | .468 |
| Reaction Time | 0.57 (0.04) | 0.56 (0.07) | 0.880 | .395 |
| Impulse Control | 6.43 (6.06) | 13.57 (13.03) | -1.955 | .072 |
| TMTA | 25.62 (6.72) | 25.04 (9.53) | 0.236 | .817 |
| TMTB | 61.06 (15.22) | 56.65 (25.62) | 0.720 | .484 |
| Digits Forward | 10.50 (1.65) | 10.50 (1.65) | 0.000 | 1.000 |
| Digits Backwards | 7.21 (1.67) | 6.50 (2.25) | 1.072 | .303 |

*Note.* $^*p < .05$.

Table 18

Dependent t-test for comparisons of Backs Pre-season versus Backs Post-season (reduced sample) including scores for ImPACT 3.0, Trail Making Test A and B and Digit Span.

| Paired Samples | Backs Pre-Season (n = 9) Mean (SD) | Backs Post-Season (n = 9) Mean (SD) | *t-value* | *p-value* |
|---|---|---|---|---|
| Verbal Memory | 88.89 (10.15) | 90.56 (6.29) | -0.731 | .485 |
| Visual memory | 78.56 (14.76) | 77.44 (16.25) | 0.471 | .650 |
| VMS | 38.17 (7.00) | 36.68 (5.75) | 0.589 | .572 |
| Reaction Time | 0.57 (0.04) | 0.55 (0.07) | 1.860 | .100 |
| Impulse Control | 6.56 (5.81) | 11.78 (6.08) | -2.660 | .029* |
| TMTA | 23.83 (6.68) | 22.76 (5.73) | 0.322 | .756 |
| TMTB | 61.21 (14.53) | 49.19 (15.59) | 1.832 | .104 |
| Digits Forward | 10.00 (1.58) | 10.33 (1.58) | -0.667 | .524 |
| Digits Backwards | 7.11 (1.62) | 7.11 (2.47) | 0.000 | 1.000 |

Note. *p < .05.

# 4. DISCUSSION

## 4.1 Introduction

The current study sought to determine whether there is any evidence for the presence of chronic cognitive effects of repetitive mild traumatic brain injury (cumulative concussions and sub-concussive episodes) in top team university level rugby players. Additionally, the study aimed at establishing whether there is evidence for a combination of acute and chronic effects due to participation in rugby at the university level due to an eight month season and prior history of playing rugby for a number of years (high school into university). Moreover, the rugby forwards versus backs in acute and chronic conditions were also investigated to determine if either group would show significant cognitive impairment when compared with one another. It was hypothesised that rugby players would perform worse than controls because they are likely to have more exposure to multiple concussive and sub-concussive head injury and that this in turn would depress cognitive functioning in tests sensitive to the effects of the diffuse pathology associated with MTBI. At the professional level of play, forwards appear to become more vulnerable than backs to concussive injury. It was not expected that positional play would be established sufficiently to differentiate between the forwards and backline groups at the university level of play.

## 4.2 Rugby players versus controls across all tests.

*Independent statistical analyses* at the pre- and post-season intervals revealed support for greater cognitive deficit amongst rugby playing groups in relation to controls in the areas of processing speed, working memory and impulse control (see Tables 7 and 8). *Dependent statistical analysis* at the pre- versus post-season for rugby and controls (see Tables 11, 12, 13 and 14) across the tests indicated that rugby players remained relatively stable between pre- versus post testing intervals on the large sample (see Table 11) (even though there were seven slight improvements in scores, these were not significant), whereas controls showed significant improvements (see Table 13), in three of the tests, namely Trail Making Test A and B and Digits Backwards. This was true for both the large and better controlled reduced sample (see Table 14), where Trail Making Test B and Digits Backwards were significant, with Trail Making Test A nearing significance ($p$ = .059). Hence, in broad terms there appears to be a replication of findings across the large and reduced samples, suggesting that the findings are likely to be explicable in terms of differences in age, estimated IQ or education levels. Hence a replication of findings was found on both the large and reduced sample, suggesting that the findings cannot be explained by differences in age, estimated IQ or education levels. Rather, findings appear explicable in terms of the highly significant differences in the number of concussions between the rugby and control groups seen for both the large and reduced samples (with a range in *p* values from .010 to .001) (see Tables 1 and 2). Additionally, the range in number of concussions from one to five is clinically significant in terms of cumulative MTBI, and adds support for this being the independent variable responsible for the cognitive deficits obtained on objective testing. The absence of practice effects in the rugby group adds support to the decline in cognitive ability due to cumulative effects or subconcussive events obtained because of rugby participation. This provides strong support for prior research indicating that individuals with traumatic brain injury (as occurs in a closed head injury) do not show any practice effect (McCaffrey, Ortega, Orsillo, Nelles & Haase, 1992; Mitrushina & Satz, 1991; Rapport, Brookes-Brines, Axelrod & Theisen, 1997; Shatz, 1981). More pronounced practice effects for the control group relative to the rugby group were also noted by Shuttleworth-Jordan et al. (1993), in the areas of processing speed (Trail Making Test A).

The comparisons of dependent samples for rugby pre-season versus rugby post-season revealed no statistical significant differences nor any consistent trends across the scores (see Tables 11 and 12). In contrast, the control group analyses indicated significant changes for Trail Making Tests A and B (p=. 036 and p= .001 respectively) and Digits Backwards (p= .018) (see Figures 1 – 3), in the direction of improved performance for controls between pre- and post-season intervals. Where the controls have become faster, rugby players remained relatively the same for Trail Making Test A (see Figure 1). In respect of Trail Making Test B, both rugby and controls improved with practice, albeit the rugby group remains considerably slower than the controls at both intervals (see Figure 2). Additionally, the controls on digits backwards improved significantly more than the rugby (see Figure 3).

*Figure 1.* Rugby (pre-and post-season) versus Controls (pre- and post-season) for Trail Making Test A.

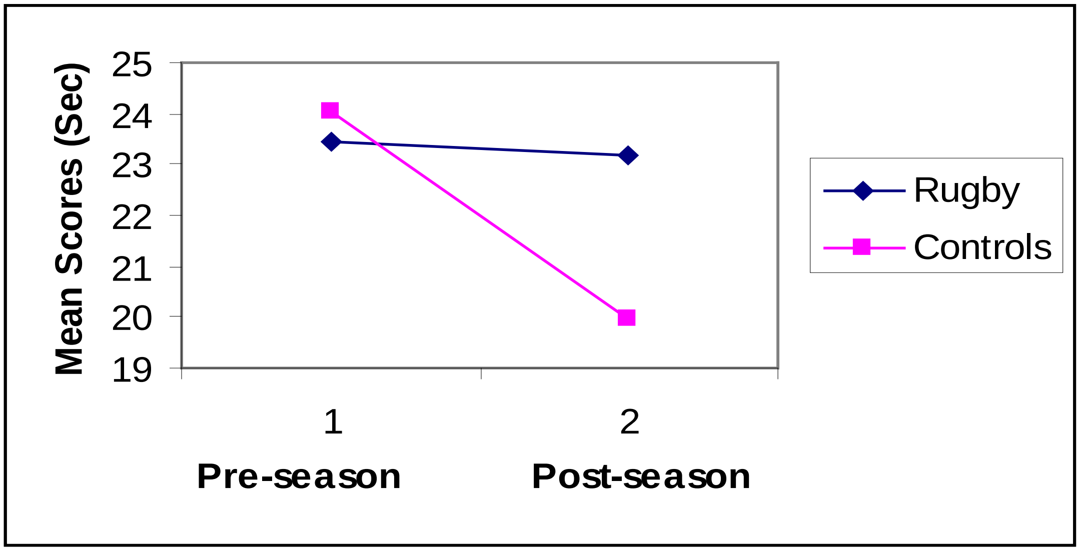



*Figure 2.* Rugby (pre-and post-season) versus Controls (pre- and post-season) for Trail Making Test B.

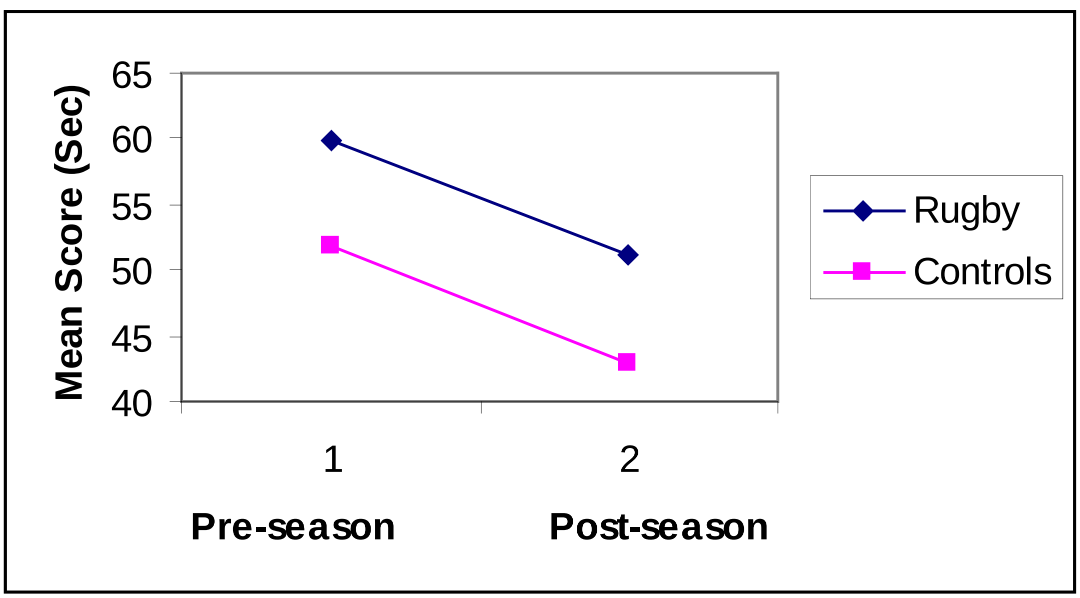
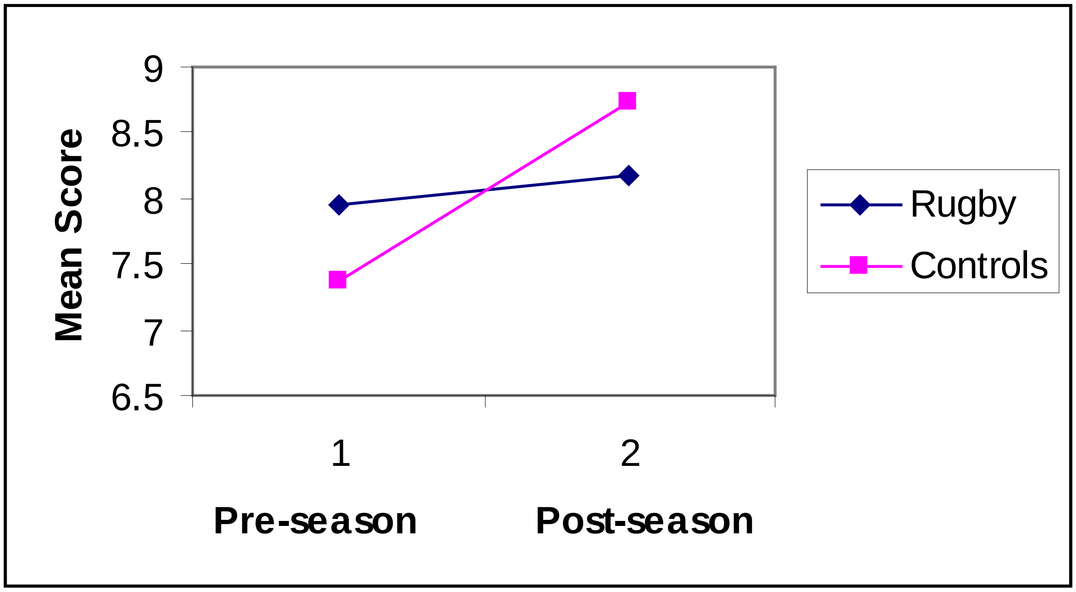


*Figure 3.* Rugby (pre-and post-season) versus Controls (pre- and post-season) for Digit Span Backwards.




These significant results support the presence of a substantial practice effect on both these tests (TMT and Digit Span) as reported by other research (Levin, Miller, Becker, Selness & Cohen, 2004). The effects of repeated tests has been studied in both brain injured and control subjects (McCaffrey et al., 1992; McCaffrey, Ortega & Haase, 1993) where in the control group, an overall pattern of test susceptibility to practice effects emerges. These tests have a large speed component and require an unfamiliar practiced mode of response, or have a single solution that can be easily conceptualised, show significant practice effects (Barr, 2003; Basso, Bornstein & Lang, 1999; McCaffrey et al., 1993).

The problem of practice effects is noteworthy in memory testing since repeated testing with the same tests leads to learning of the material in all but seriously memory impaired patients (Benedict & Zgaljardic, 1998). The absence of practice effects on tests when the effect is expected, is clinically meaningful in that scores suggest an actual decrement in learning ability, and even mildly lowered scores on tests typically vulnerable to practice effects suggests a deteriorating process (Knight, 1992). Thus, the absence of practice effects in the rugby cohort is strongly suggestive of cognitive fall off due to concussive events sustained throughout the eight-month season and prior history of playing. These deficits are typically associated with the cumulative diffuse brain damage effects of the concussive head injury for which rugby players are especially at risk, with ratification in the present sample showing a significantly higher number of reported concussions than a non-contact sports control group. These results support research carried out by Shuttleworth-Jordan et al. (1993), who also found significant practice effects with regard to controls at pre-season and post-season and comparatively with the Trail Making Tests A and B (see Table 19).

Table 19

Independent t-tests for comparisons of Controls pre-season versus Controls post-season.

| | Controls Pre-season n = 25 Mean (SD) | Controls Post-season n = 15 Mean (SD) | *t-value* | *p-value* |
|---|---|---|---|---|
| TMT A | 19.17 (2.33) | 17.30 (1.88) | 2.639 | .012* |
| TMT B | 42.51 (8.10) | 37.29 (5.95) | 2.164 | .037* |
| Digits Forward | 6.72 (0.94) | 7.13 (0.83) | -1.406 | .168 |
| Digits Backwards | 5.28 (1.21) | 5.80 (0.94) | -1.425 | .162 |

*Note.* From "Negative consequences of mild head injury in rugby: A matter of concern", by A. B. Shuttleworth-Jordan et al., 1993.
$*p < .05$.

In contrast, scores on ImPACT 3.0 subtest composites for the rugby group remained relatively stable showing no significant differences between the pre-and post testing sessions (see Tables 11 and 12), nor any particular trends (improving or getting worse). However, of note here, is the absence of practice effects in ImPACT 3.0 for either rugby or controls, which suggests that its composite scores are not subject to the large practice effects as seen on the traditional paper and pencil tests of Digit Span and The Trail Making Tests, as has been indicated in prior studies (Collie, Darby & Maruff, 2001; Iverson et al., 2002; Schatz et al., in press; Schatz & Zillmer, 2003).

Overall, the results on the independent samples are supported by the results found on the dependent samples. Whilst groups were not well controlled for age and education on the large sample (see Table 1), there was equivalence for these variables on the reduced sample (see Table 2) suggesting that age, education and estimated IQ differences were not the influential variables contributing to these results (estimated IQ was well controlled in respect of both the large and reduced samples). Rather, the significant differences are explicable in terms of the significantly greater numbers of concussions reported in the rugby group (see Tables 1 and 2). Dependent sample analyses add to the likelihood that the effect of concussions is responsible for these significant findings. Thus overall, the results of the present research provide strong support for the cumulative lingering effects of repetitive MTBI as reported by Collins, Grindel et al. (1999), Guskiewicz et al. (2003) and Iverson, Lovell et al. (in press).

Finally, it is important to note that whilst these results do appear to support the hypothesis that rugby players do not perform as well as the control group and that the likely hypothesis is that this is due to the higher number of concussions in the rugby group, the influence of pre-selected variables in this study cannot be ruled out. A well-controlled longitudinal study that follows up rugby players is needed to ensure that there are no inherent differences in cognitive style between these two groups of sportsman in the first instance. However, the fact that a test of estimated IQ was equivalent across the two groups makes it appear less likely that pre-selected effects can account for specific deficits shown for the rugby players on tests sensitive to diffuse brain damage.

Other debatable differences between groups might be due to variables that may have been operative at the time of testing, such as poor motivation, fatigue, transient effects of too little sleep or too much ‘partying’. However, as mentioned earlier, information regarding these factors that may have interfered with testing were monitored with the aid of questions from Section B (Current Symptoms and Conditions) of the pre-season questionnaire (see Appendix B), which required participants to answers questions with regard to hours of sleep, current medications and average alcohol on a daily and weekly basis. Additionally, information from the last section of the ImPACT programme was used and required the participant to list any problems they may have been experiencing at the time of testing. Using these two checks, no exclusions were deemed necessary for these factors discussed above. Hence, although it is possible, it seems unlikely that any such undisclosed factors would have been true only for the rugby group rather than the control group.

### 4.3 Rugby forwards versus rugby backs across all tests.

On independent t-test analyses (see Tables 9 and 10), test results indicate largely no significant difference between forwards and backs, supported by the lack of significant differences in the number of concussions between the forwards and backs (pre-season $p = .189$ and post-season $p = .311$) (see Tables 3 and 4). It appears that due to the shortage of players at the university level and the high rate of alternate injuries, players were required to adapt their positional play as was needed throughout the season. Positional stances were therefore less entrenched than occurs at the professional level where the hypothesis would have been true (Shuttleworth-Edwards et al., 2004). As a result of this, positions were less permanent and no significant differences were noted amongst forwards versus backs except in an isolated significant incident where forwards were noted as having a higher score with regard to digits forwards ($p$ = .019) (see Table 9). Prior research show forwards to do more poorly than backs because of scrumming and their greater exposure to collisions (Shuttleworth-Edwards et al., 2004). This isolated significant result then goes against expectations and previous findings. Furthermore, Digits Forwards is not usually a test that is singled out to be particularly sensitive to diffuse brain damage compared with Digits Backwards and the Trail Making Tests. Therefore, on its own and in the absence of any commensurate tendencies this result is likely to be a chance effect and have little interpretive validity. Of interest however, is that on dependent t-test analyses neither the forwards (see Tables 15 and 16) nor the backs (see Tables 17 and 18) revealed any significant or approaching significant improvements at the post-season versus pre-season test intervals for the Trail Making Tests, as would be expected due to practice effects, and which were revealed for the control group (see Tables 13 and 14). From this it can be extrapolated that rugby players are performing more poorly than the controls. Accordingly Rutherford, Stephens, Potter and Fernie (2004), found similar findings for demonstrated poorer performance in test scores for rugby players, due to MTBI and also on Trail Making Test B. This absence of practice effects is supportive of cognitive fall off and hence evidence for the cumulative effects of concussive events obtained whilst playing rugby.

# 5. OVERALL IMPLICATIONS OF RESULTS

## 5.1 Summary

In sum, the results suggest compelling evidence across both the independent and dependent test analyses, in the direction of support for the primary hypothesis that rugby players who sustain repetitive concussions will show more impairment than non-contact sport controls. The results of this study on closely matched samples for the variables of estimated IQ (large and reduced sample), age and education (reduced sample) may be considered suggestive of the cumulative, lingering effects of multiple concussions in university level rugby players. The most robust findings for the deleterious effects of concussion and sub-concussive events on rugby players appears in the areas of speed of information processing, working memory and impulse control, which accords with other prior sports studies (Collins et al., 1999; Erlanger et al., 1999; Guskiewicz, Ross & Marshall, 2001; Schatz et al, in press). These results were found on both the IMPACT 3.0 and paper and pencil test measures.

The findings of this study gain potency within the postulates of brain reserve capacity (Satz, 1993). This theory alerts to the potential of sub-concussive events which become apparent over time, where extended exposure to rugby associated with prior cognitive vulnerability produces further cognitive fall off. This cohort of university students is relatively protected due to their above average estimated IQ. However, despite the protective reserve relative to estimated IQ in this university population, the susceptibility in the rugby group to concussive injury increases the individual's vulnerability to functional impairment, which accounts for the deleterious cognitive effects in this group. This is commensurate with prior research that indicates that a history of two or more concussions can result in the lowered cognitive tests scores and potentially more severe sequelae resulting from a concussive injury (Collins et al., 1999; Collins Field et al., 2003). In the present study, the rugby group in the reduced sample had an average of two concussions; fourteen rugby players were diagnosed with a history of two or more concussions, six players reported a history of two concussions, three a history of three concussions and five players a history of four concussions (bearing in mind that most rugby players under report their concussion history). Thus in terms of BRC, these findings provide compelling evidence for possible lingering vulnerability from an earlier injury contributing to significant cognitive declines, as was found in the present rugby cohort.

Results from this research add support, also for evidence of neuronal dysfunction that has come from animal models where the role of multiple concussive and sub-concussive events has resulted in neurocognitive impairment (Wojtys et al., 1999). Thus against the background of theoretical expectations and prior animal and sports related research, the current research indicates a strong correlation between the role of multiple concussive and sub-concussive events and neurocognitive impairment as a consequence of participation in rugby amongst university level players.

## 5.2 Conclusion

In conclusion, the present study on university level rugby union players appears to be the first to show that ImPACT 3.0 (a computer-based test battery) is sensitive to the chronic effects of concussion. ImPACT 3.0 has shown itself to have both positive and negative properties in terms of its ability to be sensitive to MTBI. ImPACT 3.0 was seen to be sensitive to the sequelae of concussion, as evidenced in the pre- and post-season independent t-test analyses, and was not vulnerable to the practice effects evident on the dependent test analyses, which contributes to the overall support in this study, where the rugby group was seen to have difficulties within a number of cognitive modalities. In concussion management, the absence of practice effects may be seen as an asset compared with the traditional paper and pencil tests, which were seen to be vulnerable to practice effects. With the presence of practice effects, test scores may be seen to return to baseline before concussion symptoms have ameliorated, and thus give the false impression that an athlete may return-to-play (Collie et al., 2001). Finally, the present study has implications for the use of ImPACT 3.0 in a concussive setting, in that (i) it showed itself to be comparatively sensitive to the residual effects of concussion as shown by the traditional well researched paper and pencil Trail Making and Digit Span Tests, and (ii) it differs from the traditional paper and pencil tests in not showing practice effects. This is beneficial in the concussion arena, where tests which show practice effects may give a false impression that an athlete may return-to-play, even though symptoms have not resolved completely, thus putting them at risk for the deleterious effects of concussion and even second impact syndrome.

## 5.3 EVALUATION OF RESEARCH

### 5.3.1. Methodological Strengths

Strict exclusion criteria were used in this study in terms of possible variables which might contribute to the cognitive deficits which may increment the results obtained, these included; any neurological or psychiatric disorder, substance abuse problem, present medication and any athlete with previous moderate to severe head injuries, or a concussion (MTBI) within the season. Furthermore, a strength of the study was that an estimated IQ was obtained and comparative groups were equivalent for estimated IQ so that results could be matched on the basis of age and education. These were broadly controlled for in the large sample which was restricted to an age range of 18-24 years. Fine control was then obtained by restricting the large sample in order to prevent extraneous variables from confounding the findings. Moreover, a record of concussions was elicited from the rugby group so that it was possible to provide evidence for the significant high number of concussive incidents relative to the control group. This hard data was used as an independent variable to confirm the hypothesis that the rugby group would be more exposed to the effects of concussion than the control group. Multiple measures were also used in the cross sectional research, which was supplemented with a preliminary prospective between the pre- and post-season testing intervals.

### 5.3.2 Methodological weaknesses.

The study is limited in its relatively small size, creating a vulnerability to a type II error (failing to find significance when it is present). Despite the small sample however, there were significant findings in the direction of the primary hypothesis, and these were replicated across the large and reduced sample. Additionally, if using multiple measures with the same data the use of a Bonferroni adjustment should be considered to avoid making a type I error (finding significance when it is not present). However, the present study used relatively few measures, on participants who were expected to show subtle findings due to MTBI in sport at the university level. The use of the Bonferroni adjustment would then have increased the likelihood of making a type II error (failing to find significance when it is present). In this study far fewer measures were analyzed compared with other studies targeting chronic effects of sport MTBI, (for example Matser et al., 1998 and Rutherford et al., 2004) where their research conducted in excess of sixteen multiple measures and no Bonferroni adjustments were made. It was therefore decided not to use the Bonferroni adjustment at this relatively exploratory stage of looking at MTBI in rugby, in order to protect against making a type II error, thereby failing to identify cognitive decrements in association of sport MTBI worthy of further investigation.

An exclusion criterion was any individual who obtained a concussive injury during the season. However, it may have been possible that some rugby players who may have been concussed during the season (study period) were not identified, or failed to disclose, either on purpose or due to their inability to recognise the signs and symptoms of concussion. It however seems hardly feasible that individuals with this particular spectrum of cognitive decrements, and the type of rugby cohort involved, that such concussive events would go unnoticed. In addition, it is also difficult to draw an exact line between a mild and sub-concussive episode. In any event, players did not actually show any worsening at post-season, and hence it is doubtful that any under reporting took place. Furthermore, the estimated pre-morbid IQ scores were based on only two subtests of the WAIS-III due to time constraints. A wider range of tests would have been preferable in estimating the pre-morbid IQ. However, it is of note that many studies only use education level and not an IQ score in their studies. The use of two subtests made the present study relatively robust for the screening of estimated IQ, which is an advantage over many prior studies, which in fact do not use any IQ score, but rather matched education level as described earlier.

Finally, although no raw data can be truly devoid of extraneous variables, subject variables can become a problem especially in independent measures design, creating random or even constant confounding effects. In the present study, to ensure that the two groups of sportsman (rugby players and controls) were not inherently different in the first instance, thereby creating a constant confounding effect, participants were matched for IQ levels across the two groups and other arguable differences between the groups that might have been operative at the time of testing, such as poor motivation, fatigue, transient effects of too little sleep or too much ‘partying’ were monitored. Thus, while it is possible, it seems improbable inherent weaknesses in cognitive ability, and any undisclosed test-taking factors, would have been true for only the rugby group in this sample rather than the control group.

### 5.3.3. Recommendations for further research

Further research should be extended to both males and females as for example, prior statistical analyses has revealed a number of significant gender differences in neuropsychological test scores on brain damaged populations (Barr, 2003; Halpern, 1997). Future research with larger, more homogenous samples are needed to provide further affirmation of the results obtained. The present largely cross-sectional study has provided a measure of evidence for the deleterious effects of MTBI in association with participation in rugby. However, given the problem of pre-selected effects that are inherent in this type of study, long-term prospective studies on rugby players versus equivalent non-contact sports controls ranging from high school level into university level are needed need to provide more certainty on the issue of chronic effects of cumulative MTBI as a consequence of long-term participation in rugby. Research is encouraged with larger sample numbers to replicate and expand upon this research at longer intervals and across seasons for the recovery of concussions, and to strengthen the supposition of this study.

The study defined good post-season presentation based upon empirically defined change in ImPACT and the two traditional tests on university athletes, but it could be widened to other age groups and cultural groups relevant to the South African context. A wider range of cultural groups, levels of education and IQ might present a more vulnerable group (lower cognitive reserve) to the deleterious cognitive consequences of concussion.

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Appendix A
Consent Form

Dear Rugby/Hockey/Cricket /Swimming member
**RHODES UNIVERSITY RESEARCH STUDY: CONCUSSION IN SPORT**

In keeping with the need to maximize the safety of sports players generally, and particularly in the contact sports where there is a known risk of concussion, it has been decided to implement the latest internationally approved risk prevention strategies for concussion for top team rugby and hockey players at Rhodes University. *The initiative has the full support of the Director of Sports Administration, Peter Andrew, who believes that the study will (i) provide short-term benefit to concussed players, and (ii) in the long-term contribute to the refinement of sports 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. Our objective is to initiate an innovative study, which aims to develop such facilities within the South African school and university contexts, which are already extensively in place in sports playing institutions in countries such as the USA, Australia and New Zealand. Consequently, you will have the unique opportunity to participate in this groundbreaking research by clinicians at Rhodes University, who are working in collaboration with the University of Pittsburgh Medical School, USA and the MRC/UCT Research Unit for Exercise Science and Sports Medicine, Newlands, South Africa.

Members of the top two rugby and hockey teams will be the first to participate in this monitoring and risk prevention project at university level. Measuring for the effects of any past or future concussions will take place pre and post winter sport season using scientifically valid computerized screening systems developed in the USA specifically for concussion management. Screening will involve the evaluation of functions such as memory, reaction time and processing speed and will take the form of simple paper and pencil exercises and computer games. These are usually enjoyable and take 40 minutes to complete. In addition, you will be asked to provide a brief medical background and complete a symptom checklist, with relevance to the research. There will be ongoing sports concussion monitoring through the winter season and appropriate intervention. In the event of a concussion, follow-up evaluation of concussed players will take place within 6 days of injury and then again at weekly intervals, until acute symptoms resolve. The data will be examined by researchers at Rhodes University and if the outcome proves favourable in terms of minimizing risk to players, the strategy will be considered for future use at top team levels where there is a higher injury risk. The results of the research will be used for scientific publication purposes only by the collaborating universities.

It is important to be aware that this study does not interfere with or substitute for good medical practice. We therefore advise that all individuals with concussion should be seen as soon as possible by their general practitioner or other medical practitioners 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 players will be strictly confidential and will only be made available to individuals 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 individual players on the basis of that information. We believe that it is to your benefit to participate in this concussion risk prevention project. However, participation is voluntary and you have the right to withdraw form the entire project or part thereof if you so wish. Non-participation in this study will exclude you from the benefit of computer-based cognitive screening in the event of a concussion.

Yours sincerely

_____________________ _____________________

**Prof Ann Edwards (Research Coordinator)** **Peter Andrew (Director: Sports administration)**

Researcher _________________ Researcher ___________________ Researcher ______________

**RHODES UNIVERSITY**
**DEPARTMENT OF PSYCHOLOGY**

## CONSENT FORM

*I, ________________________________ have been informed of the nature of the research which will be conducted by three Rhodes University masters students, Ian Smith, Melissa Boulind and Stephanie Case, on the effects of concussion in University rugby.*

**I understand that:**

1) The above mentioned students are conducting the concussion management research as a requirement for a MA degree at Rhodes University in collaboration with the University of Pittsburgh Medical School, USA and the MRC/UCT Research Unit for Exercise Science and Sports Medicine, Newlands, South Africa. The research has the full support of the Rhodes University Director of Sports Administration, Mr Peter Andrew.

2) The research will involve all willing members of the top two rugby and hockey teams at Rhodes University. Team members will be assessed for the effects of any past or future concussions using internationally validated computer-based neuropsychological screening batteries, pre and post winter sport season. In the event of a concussion, a follow-up assessment will take place within 6 days, of injury and then again at weekly intervals, until acute symptoms resolve. In addition, individuals will be requested to fill out a brief demographic questionnaire with medical background and a symptom checklist, with relevance to the research.

3) This study does not interfere with or substitute for good medical practice. It is therefore advised that in the event of a concussion, individuals should be seen as soon as possible by a general practitioner or other medical practitioners 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.

4) Participation in the research is strictly voluntary. Individuals have the right to withdraw from the study at any stage, although by not participating in the project, no base-line scores or concussion follow-up by the researchers will be available for that player.

5) The information collected on individual players will be strictly confidential and will only be made available to the participants 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 participants on the basis of that information.

6) Data arising out of this project will be used for thesis and publication purposes only by the collaborating universities.

**Signed:** ___________________________ **Date:** _________________________

**Name:**______________________ **E-mail:** _______________________

**Address:**__________________________________________________________________

**Contact Telephone Number(s):**_____________________ _______________________

# RHODES UNIVERSITY

## DEPARTMENT OF PSYCHOLOGY

### BRIEF TO RUGBY/HOCKEY/CRICKET PLAYERS AND SWIMMING TEAM MEMBERS REGARDING CONCERNS ABOUT PARTICIPATION IN CONCUSSION RESEARCH

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

1. The participant has the right to withdraw from the entire project or any part thereof. Withdrawal from the project will not prejudice him in any way in terms of his position in team sport.

2. Withdrawal from the project must occur in writing. The participant must complete the withdrawal form below.

3. We wish to emphasize that the project is neither invasive nor harmful to the participant'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 the participant's 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 player.

5. Should the player participate in a sport where there is not a great head injury risk, his participation is still of crucial benefit to the research. This is in order to make comparisons between players who are exposed to sports concussion, and those who are not exposed. Moreover, should the participant 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.

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**WITHDRAWAL FORM**

I, ___________________________________ hereby wish to withdraw from participating in the university's concussion project. I am aware of the possible negative consequences to my well-being in declining computer-based monitoring in respect of concussion.

**SIGNED: ___________________________**

**DATE: _____________________________**

Appendix B
Pre-season Questionnaire

***CONFIDENTIAL***

First Names: ______________________ Surname: ______________________

Date of Birth: ______________________ Age: ______________________

Highest educational qualification: ______________________

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

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

***A. BACKGROUND INFORMATION***

Last school attended: ______________________

Height: __________ m Weight: __________ kg

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

Country of birth: ______________________ First Language: ______________________

Second Language: ______________ Years speaking second language: ______________

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

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

What winter sport(s) do you play?

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

How many times have you sustained a concussion (i.e. felt dazed, dizzy or confused, however briefly, or unconscious)? ______________________________

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

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

Please indicate whether you have experienced the following:

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

### *B. CURRENT SYMPTOMS AND CONDITIONS*

Hours of sleep last night ____________________

Current medications ______________________________________________

Average weekly alcohol consumption ____________________________________

Average daily alcohol consumption _____________________________________

Appendix C
Protocols

Digit Span

| DIGITS FORWARD | TRIAL SCORE | ITEM SCORE | DIGITS BACKWARDS | TRIAL SCORE | ITEM SCORE |
|---|---|---|---|---|---|
| 1. | | | 1. | | |
| 1 – 7 | | | 2 – 4 | | |
| 6 – 3 | | | 5 – 7 | | |
| 2. | | | 2. | | |
| 5 – 8 – 2 | | | 6 – 2 – 9 | | |
| 6 – 9 – 4 | | | 4 – 1 – 5 | | |
| 3. | | | 3. | | |
| 6 – 4 – 3 – 9 | | | 3 – 2 – 7 – 9 | | |
| 7 – 2 – 8 – 6 | | | 4 – 9 – 6 – 8 | | |
| 4. | | | 4. | | |
| 4 – 2 – 7 – 3 - 1 | | | 1 – 5 – 2 – 8 – 6 | | |
| 7 – 5 – 8 – 3 - 6 | | | 6 – 1 – 8 – 4 – 3 | | |
| 5. | | | 5. | | |
| 6 – 1 – 9 – 4 – 7 – 3 | | | 5 – 3 – 9 – 4 – 1 - 8 | | |
| 3 – 9 – 2 – 4 – 8 – 7 | | | 7 – 2 – 4 – 8 – 5 - 6 | | |
| 6 | | | 6. | | |
| 5 – 9 – 1 – 7 – 4 – 2 - 8 | | | 8 – 1 – 2 – 9 – 3 – 6 – 5 | | |
| 4 – 1 – 7 – 9 – 3 – 8 - 6 | | | 4 – 7 – 3 – 9 – 1 – 2 - 8 | | |
| 7. | | | 7. | | |
| 5 – 8 – 1 – 9 – 2 – 6 – 4 - 7 | | | 9 – 4 – 3 – 7 – 6 – 2 – 5 - 8 | | |
| 3 – 8 – 2 – 9 – 5 – 1 – 7 - 4 | | | 7 – 2 – 8 – 1 – 9 – 6 – 5 - 3 | | |
| 8. | | | | | |
| 2 – 7 – 5 – 8 – 6 – 2 – 5 – 8 - 4 | | | | | |
| 7 – 1 – 3 – 9 – 4 – 2 – 5 – 6 - 8 | | | | | |
| Digits Forward Total Score (Max = 16) | | | Digits Backwards Total Score (Max = 14) | | |

Forwards + Backwards = Total (max = 30)