THE CLINICAL REACTION TIME TEST AS PART OF A STANDARDISED CONCUSSION ASSESSMENT BATTERY

by

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DECLARATION

I, CHARL SAREL VON WILLIGH CARSTENS, hereby declare that the work on which this dissertation is based, is my original work (except where acknolwedgements indiciate otherwise) and that neither the whole work or any part of it has been, is being, or has to be submitted for another degree in this or any other University.

It is being submitted for the degree of Masters of Sports Medicine in the School of Medicine in the Faculty of Health Sciences of the University of the Free State, Bloemfontein.

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ABSTRACT

Background: Concussion is a worldwide challenge and diagnosing, evaluating and monitoring injured athletes places a huge burden on even experienced clinicians. Each concussed athlete presents differently and each one should be treated individually. In an ideal world, enough resources should be available for neuropsychologists and neuropsychology tests to evaluate each athlete. In resource-limited areas, neuropsychologists are replaced by experienced clinicians for treating concussions; these clinicians use as many objective cognitive tests as are available. If computerised neuropsychology tests are unavailable, then low-cost, objective and fast sideline tests, like the clinical reaction time test, may be incorporated in the assessment battery protocol. No one test can be the sole cognitive assessment for recovery after a concussion. It is imperative that all these clinical tests practical limitations and benefits are known.

Aims: This study's primary aim was to compare the Sport Concussion Assessment Tool 3 (SCAT3) total score with the clinical reaction time test (RT_{Clin}). The secondary aim was to compare the two tests as recovery tracking evaluations in the days following a concussion.

Methods: In one season (2014) a prospective cohort study of amateur collegiate rugby union players who suffered concussion (n = 46, mean age 21, range 18 to 33 years) out of 1 166 registered players were evaluated within 72 hours (Evaluation-1), then weekly (Evaluations 2 to 4) until they became asymptomatic (Evaluation-Asymptomatic) using the SCAT3 total score and RT_{Clin} tests.

Results: Within the first 72 hours after a concussion the SCAT3 Score and the RT_{Clin} showed a moderately positive correlation of 0.47 (Spearman test) and $p = 0.04$. The Spearman correlation between asymptomatic athletes was poor (0.21 and $p = 0.46$).

A comparison of the SCAT3 Score of the first evaluation (E-1, n = 19, mean 24, range 10 to 74) with the asymptomatic evaluation (E- Asym, n = 14, mean 3.5, range 0 to 9) shows statistical significance ($p < 0.01$). The RT_{Clin} during E-1 (n = 19, mean 190 ms, range 168 to 258 ms) and, compared to E-Asym (n = 14, mean 179 ms, range 147 to 223 ms), came close to showing significance ($p = 0.07$).

The recovery tracking showed the mean time for recovery as 6 days (n = 5, range 4 to 18 days). The SCAT3 Score for E-1 showed a mean of 24, E-Asym mean of 3 and mean

difference of 18. The RT_{Clin} for E-1 showed a mean of 199 ms, E-Asym mean of 178 ms and a mean difference of 20 ms. There is a strong correlation of SCAT3 Score and RT_{Clin} over time, of 0.80, but $p > 0.05$. The recovery time correlation for SCAT3 Score was moderate (-0.56), but $p > 0.05$, and for RT_{Clin} recovery showed a strong correlation over time (-0.82), but also $p > 0.05$.

Conclusions: In a low-resource environment with only clinical examinations, SCAT3 and RT_{Clin} as tools there is evidence that the SCAT3 Score and RT_{Clin} may be good sideline diagnostic or screening tools within the first 72 hours after concussion. When athletes become asymptomatic, the RT_{Clin} becomes more important for monitoring persistent cognitive impairment than the SCAT3 Score. Further research is needed with larger study populations to confirm the utility of the RT_{Clin} as part of a post-concussion assessment battery.

LIST OF ABBREVIATIONS AND ACRONYMS

ADHD	**Attention deficit hyperactivity disorder**
ANAM	**Automated Neuropsychological Assessment Metrics**
BESS	**Balance Error Scoring System**
CC	**Corpus Callosum**
CogSport	**CogState Sport**
CONSORT	**Consolidated Standards of Reporting Trials**
CT	**Computerised tomography**
CTE	**Chronic traumatic encephalopathy**
DAI	**Diffuse axonal injury**
DSM-4	**Diagnostic and Statistical Manual of Mental Diseases 4th edition**
E-Asym	**Evaluation Asymptomatic**
GCS	**Glasgow Coma Scale**
ICD-10	**International Classification of Diseases 10th revision**
ImPACT	**Immediate Post-Concussive Assessment and Cognitive**
MBESS	**Testing Modified Balance Error Scoring System**
ms	**Milliseconds**
mTBI	**Mild traumatic brain injury**
PCSS	**Post Concussion Symptom Score**
RT	**Reaction Time**
RT_{Clin}	**Clinical Reaction Time**
RTP	**Return to play**
SAC	**Standardized Assessment of Concussion**
SCAT3	**Sport Concussion Assessment Tool 3**
SIS	**Second impact syndrome**
SRC	**Sport-related concussion**
SRFC	**Stellenbosch Rugby Football Club**
SRT	**Simple Reaction Time**
USA	**United States of America**

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CHAPTER 1

INTRODUCTION TO STUDY

1.1 INTRODUCTION

In recent years the world has seen a dramatic increase in media coverage of sport-related concussion (SRC), and chronic traumatic encephalopathy, in particular, has received renewed attention. Research in SRC developed exponentially after the first International Conference on Concussion in Sport was held in Vienna in 2001 (Aubry, Cantu, Dvorak *et al.* 2002). At this conference clinicians around the world involved in ensuring the health and safety of athletes acknowledged the numerous challenges they faced after an SRC event (Aubry *et al.* 2002). The first consensus agreements on definition, evaluation, rehabilitation and treatment protocols were proposed (Aubry *et al.* 2002).

More recently, the 4th Conference developed and updated recommendations and introduced the latest update of Sport Concussion Assessment Tool 3 (SCAT3) (McCrory, Meeuwisse, Aubry *et al.* 2013). The SCAT3 consists of several individual tests, which incorporate a severity assessment (Glasgow Coma Scale (GCS)), orientation and memory score (Maddocks questions), physical sign score, symptom assessment (Post Concussion Symptom Score (PCSS)), mental status assessment (Standardized Assessment of Concussion (SAC)) and balance testing (Modified Balance Error Scoring System (MBESS)) (Guskiewicz, Register-Mihalik, McCrory *et al.* 2013). When these tests are grouped together and summarised and the resulting score may be called a SCAT3 Score. Each individual test has good research to support its use, but at present there is insufficient evidence to support the use of the SCAT3 Score (Guskiewicz *et al.* 2013).

Recently researchers (Eckner, Kutcher, Broglio *et al.* 2014) proposed a novel, low-cost sideline test to help diagnose and evaluate SRC, namely, the clinical reaction time test (RT_{Clin}). This group of researchers conducted a pilot study in 2010, during which they compared the RT_{Clin} with the SRT of the computerised test CogState Sport (CogSport). They found a moderately positive correlation of 0.45 with $p < 0.001$ (Pearson test) at baseline (Eckner *et al.* 2010). In 2011 they tested the test-retest reliability from one season to the next once again comparing the RT_{Clin} with the SRT of CogSport (Eckner, Kutcher &

Richardson 2011). They found that the two tests showed moderate positive correlations between the seasons (0.65 and 0.51 Intra-class Correlation Coefficients respectively). Lastly, this research group investigated the diagnostic utility of RT_{Clin}, which was assessed by testing concussed athletes within 48 hours of injury and matching the athletes with a control group (Eckner *et al.* 2014). Together with baseline tests the RT_{Clin} showed a sensitivity of 75%, specificity of 68% and a reliable change confidence level of 65% (Eckner *et al.* 2014). This research group confirmed that RT_{Clin} is a valid, sensitive, specific concussion sideline test with good test-retest reliability.

There is no single test that can be used to assess SRC, and a multimodal approach is advised (Guskiewicz *et al.* 2013). Not every athlete needs to be evaluated by a neuropsychologist or undergo computerised neuropsychology tests (McCrory *et al.* 2013), but if these tests are needed and resources are limited, then experienced clinicians may use as many objective cognitive tests as are available. In a case like this the RT_{Clin} test may be included in the SRC assessment battery protocol. If new tests are included it is important to know their limitations and benefits (Eckner & Kutcher 2010).

1.2 THE AIM OF THE STUDY

This study's primary aim was to compare the SCAT3 total score with the RT_{Clin} test. The secondary aim was to compare the two tests as recovery tracking evaluations in the days following a concussion.

1.3 GOAL OF THE STUDY

The goal of the study was to evaluate the SRT test's utility in a sports concussion battery: sideline assessment within the first 72 hours, cognitive impairment tracking in the asymptomatic athlete and for its usefulness in making return to play (RTP) decisions. This test may positively influence clinical decision-making and RTP processes when used as part of a multifaceted concussion assessment battery.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The burden of traumatic brain injury on society has never been truly appreciated, with numerous authors referring to it as “the silent epidemic” (Buck 2011; Moser 2007; Feinstein & Rapoport 2000).

Concussion is a transient functional cognitive defect induced by a mechanical force. The unfortunate long-term complications of concussion have recently received much media attention, but the consequences may prove to be even more far reaching, considering that more than half of all concussions go undiagnosed (Harmon, Drezner, Gammons *et al.* 2013).

Clinicians need to consider real-world application of all available methods of concussion assessment, and to avoid depending on one single test (Grant, Janse van Rensburg, Janse van Rensburg *et al.* 2014; Barlow, Schlabach, Pheifer *et al.* 2011; Resch, May, Tomporowski *et al.* 2011; Riemann & Guskiewicz 2000). This process has been applied from the early years of each individual concussion test, from the early, expensive and impractical force-platform tests, to the development of the Balance Error Scoring System (BESS) clinical balance test (Riemann & Guskiewicz 2000). A similar process for finding a more inexpensive and practical real-world replacement for computerised cognitive tests was observed with the development of clinical reaction time tests (Eckner, Chandran, Richardson 2011).

2.2 DEFINITION OF CONCUSSION

The recent surge of research in SRC has contributed significant insight into the management of concussion. The first significant step in epidemiological research was reached at the 1st International Symposium of Concussion in Sport (Aubry, Cantu, Dvorak *et al.* 2002), with a definition of concussion. The latest understanding of concussion is that it is a subset of mild traumatic brain injury (mTBI) and not synonymous terms (McCrory, Meeuwisse, Aubry *et al.* 2013). Unfortunately the terms are still used interchangeably in North American literature (McCrory *et al.* 2013). The term commotio cerebri is still frequently used, especially in European literature (McCrory *et al.* 2013).

The 4th International Conference on Concussion in Sport defined concussion as "a complex pathophysiological process affecting the brain, induced by biomechanical forces" (McCrory *et al.* 2013). The consensus agreement identified these common features:

- Direct or indirect blow to the head.
- Neurological impairment with quick onset, short duration and which resolves spontaneously. This impairment may, in some cases, only evolve after a few hours.
- A functional rather than a structural injury, and standard neuro-imaging reveals no structural injury.
- Loss of consciousness may or may not be present and symptom resolution follows a sequential recovery pattern.

2.3 PATHO PHYSIOLOGY

Current research suggests that concussion involves linear acceleration or rotational shearing forces that cause rapid, complex neurochemical cascade mechanisms (Signoretti, Lazzarino, Tavazzi *et al.* 2011). Gross anatomical structures remain intact and SRC may be defined as a biomechanical brain injury leading to neural dysfunction, rather than a structural injury (McCrory *et al.* 2013; Signoretti *et al.* 2011).

Initially, the mechanical force exerted on neural membranes lead to ion channel and membrane defects, neuropeptide release, neural excitation, depolarisation, calcium ion release, progression to dysfunction of the mitochondria, cerebral auto regulation and blood flow (Khurana & Kaye 2012; Reddy 2011; Signoretti *et al.* 2011).

It used to be believed that diffuse axonal injury (DAI) caused the pathophysiological process of concussion, but recent research was unable to support this theory conclusively (Signoretti *et al.* 2011). The rate of reduction of simple processing speed measured by SRT was proven valuable for differentiating between more severe DAI patients and moderate DAI/control groups in the first few weeks after injury (Felmingham *et al.* 2004).

The Corpus Callosum (CC), with its long axons, is thought to be especially vulnerable during DAI and thus possibly also during concussion (Hammond-Tooke, Goei, Du Plessis *et al.* 2010). A study by Hammond-Tooke *et al.* (2010) was unable to prove CC involvement using mean reaction times during one and two-handed tasks after suffering a concussion. This study demonstrated a more intra-hemispheric cortical injury and, possibly, further evidence of the difference between the two entities (Hammond-Tooke *et al.* 2010).

Clinically concussion may still resemble the mildest form of DAI, but given the transient nature and fast resolution of most concussions, they remain distinct entities (Signoretti *et al.* 2011). These cognitive changes are usually reversible and the majority (80-90%) resolve within 7 to 10 days (McCrory *et al.* 2013).

2.4 DIAGNOSIS

Concussion remains a clinical diagnosis but current literature suggests a multimodal approach to diagnosing SRC by incorporating pre-participation concussion history, clinical symptoms, signs, behavioural changes, sleep pattern changes and cognitive deficits (Guskiewicz, Register-Mihalik, McCrory *et al.* 2013; McCrory *et al.* 2013). The clinical diagnosis may require at least a symptom checklist, cognitive assessment and a balance test (Grant *et al.* 2014) – assessments that are largely included in the SCAT3 (McCrory *et al.* 2013).

The SCAT3 was developed to help clinicians with the integration of the post-concussion clinical complex, and the third version of SCAT was updated at the 4th International Conference on Concussion in Sport in 2012 (Guskiewicz *et al.* 2013; McCrory *et al.* 2013). There is no single test or assessment vastly better than any other tool for diagnosing SRC, but it is crucial for clinicians to understand each test's weaknesses and strengths (Eckner & Kutcher 2010).

This clinical battery consists of an injury severity assessment (GCS), orientation and memory score (Maddocks questions), physical sign score, symptom assessment (PCSS), mental status assessment (SAC) and balance testing (MBESS) (Guskiewicz *et al.* 2013).

The GCS is validated and has been a widely accepted clinical instrument for head injury assessment for over 40 years, and it is used to assess risk, monitor head injury trends, and classify and predict prognosis (Teasdale, Maas, Lecky *et al.* 2014). The GCS (out of 15) is the sum of the best eye response (out of 4), best verbal response (out of 5) and the best motor response (out of 6). This score is more important immediately after an injury and less so during later evaluations, when the athlete is clearly responsive and ambulant (Guskiewicz *et al.* 2013).

The Maddocks questions were found to be more sensitive to the effects of concussion, as they refer to recently acquired information rather than standard orientation questions (Maddocks 1995). These questions and score are only recorded during the initial sideline

diagnosis and become less important as follow-up evaluations are done (Guskiewicz *et al.* 2013).

The symptom evaluation with SCAT3 consists of the PCSS graded checklist of 22 symptoms scored from 0 to 6, to a maximum of 132 (Guskiewicz *et al.* 2013). Broglio, Macciochi & Ferrara (2007) reported a sensitivity of 68% as a stand-alone test of concussion, but it is useful as a recovery tracking tool during follow up evaluations (Guskiewicz *et al.* 2013). Baseline mean values as high as 3.52 for the PCSS in men aged 17 to 32 years have been reported as a "normal" value; scores rise to a mean of 5.25 at baseline when the men had a history of previous concussion (Shehata, Wiley, Ricea *et al.* 2009).

The mental status evaluation (SAC) consists of orientation questions (out of 5), immediate memory score (out of 15), concentration score (digits backwards out of 4 and month in reverse out of 1) and delayed recall score (out of 5), to give a total score of 30. Barr and McCrea (2001) recorded a sensitivity of 94% and a specificity of 76% when they used the SAC to compare concussed and non-injured athletes. The surprising baseline mean scores recorded by Shehata *et al.* (2009) showed male athletes' immediate recall score recorded no errors, but the concentration score of repeating digits backwards showed only 51% able to complete all 4, only 90% able to complete the months in reverse correctly, and a delayed recall mean score of only 4 out of 5.

The MBESS balance evaluation, a modified version of BESS, is used in the SCAT3 tool (McCrea *et al.* 2013). The BESS tests three stances on hard and foam surfaces and has been shown to be sensitive to postural instability in the first three days after a concussion, more so on a foam surface (Riemann & Guskiewicz 2000). The MBESS tests the three stances on a hard surface only. Further research is needed to confirm the wide use of only the hard surface (McCrea *et al.* 2013).

Reliable research supports the use of each score used independently, while the total SCAT score needs more supportive research regarding its use (Guskiewicz *et al.* 2013).

2.5 EPIDEMIOLOGY

The American Medical Society of Sports Medicine's position statement of 2012 estimates that as many as 3.8 million concussions occur in sports annually in the United States (USA), but under-reporting may be as high as 50% (Harmon, Drezner, *et al.* 2013).

Concussion occurs in all sports, with the highest incidence in the US in American football, ice hockey, rugby, soccer and basketball (Hootman, Dick, & Agel 2007). The incidence of concussion reported by the National Collegiate Athletic Association among male athletes over 18 years ranged from 0.07 per 1 000-hour exposure for baseball, 0.37 for football, 0.41 for ice hockey and 0.54 per 1 000 hours for spring football (Hootman *et al.* 2000).

Rugby union is a contact sport and it is estimated that there are more than 7.23 million rugby union players in 120 countries (World Rugby 2014). The global popularity of the sport is undeniable, but the game has one of the highest incidences of injuries of any team sports (Brooks *et al.* 2005).

Cross, Kemp, Smith *et al.* (2015) report a match concussion incidence for professional rugby union players of 8.9 per 1 000 hours of rugby played. They also observed that these players had a 60% higher incidence of any injury after returning to play than their non-concussed teammates (Cross *et al.* 2015). Fraas, Coughlan, Hart *et al.* (2013) report a 44.9% incidence of SRC in one season for four professional Irish teams; 53.4% of players admitted that they did not report a possible concussion incident.

In the South African context the reported concussion incidence among adult players ranges from 1.6% by one study (Holtzhausen, Schwellnus, Jakoet *et al.* 2006) and 3% to 23% per season in another study at various institutions (Shuttleworth-Edwards, Noakes, Radloff *et al.* 2008). The incidence in youth players was reported to be 6.8 per 1 000 match hours, and it was noted that the younger groups (under 13 and 16 years) had higher rates than the under 18 year group (Mc Fie, Brown, Hendricks, *et al.* 2014).

2.6 COMPLICATIONS

Concussion is, by definition, reversible, but several factors may complicate recovery. Some animal studies indicate a “post concussive brain vulnerability” (Khurana & Kaye 2012; Signoretti *et al.* 2011) that may lead to a second impact syndrome (SIS). It is postulated that concussed cells may be damaged irreversibly in this state, leading to fatal brain oedema, although supporting evidence is still lacking (Meehan & Bachur 2009).

Persistent concussion symptoms may present in less than 15% of cases and is diagnosed when symptoms persist beyond 10 days (McCrory *et al.* 2013). Post-concussion syndrome is defined by the Diagnostic and Statistical Manual of Mental Diseases 4th edition (DSM-4)

as the persistence of symptoms beyond 3 months; however, the International Classification of Diseases 10th revision (ICD-10) requires 4 weeks of symptoms (Reddy 2011).

There have been recent claims that repetitive concussions may lead to a specific complication of chronic traumatic encephalopathy (CTE) (Stern, Riley, Daneshvar *et al.* 2011). This is described as a taupathy (neurodegeneration caused by tau protein accumulation), which manifests clinically in memory impairment, emotional disturbances, depression and suicide (Khurana & Kaye 2012; Stern *et al.* 2011). The 4th Concussion Statement cautions clinicians that causation between concussion and CTE has not yet been established (McCrory *et al.* 2013) due to the fact that diagnosis is currently made after autopsy and no randomised trial has been undertaken (Stern *et al.* 2011).

2.7 MANAGEMENT

Current literature suggest a multimodal approach to sport concussion assessment, and incorporating self-reported symptoms and cognitive and balance assessment to help clinicians to integrate the post-concussion clinical complex (McCrea, Iverson, Echemendia *et al.* 2013; McCrory *et al.* 2013). Most authors agree that serial neurological evaluations utilising the SCAT-3 tool should follow, unless a computerised tomography (CT) scan is needed to exclude a structural injury (McCrory *et al.* 2013; Khurana & Kaye 2012; McCrory, Meeuwisse, Johnston *et al.* 2009).

The Zurich consensus statement suggests a graduated RTP protocol in asymptomatic athletes after a period of rest. This period ranges between 24 hours (> 18 years), one week (16-18 years) and two weeks (< 16 years) (McCrory *et al.* 2013; McCrory *et al.* 2009). There is a stepwise progression after the rest: increased activity every 24 hours for athletes over 16 years and every 48 hours for players 15 years and younger (Grant *et al.* 2014). The RTP protocol may be completed in one week, but if any symptom recurs the athlete drops back to the previous asymptomatic level (McCrory *et al.* 2013).

The cornerstone of treatment of concussion remains both physical and cognitive rest until all symptoms resolve (McCrory *et al.* 2013; McCrory *et al.* 2009).

The gold standard of assessment, however, is still formal neuropsychological testing by a neuropsychologist (McCrory *et al.* 2013). However, these tests are substituted worldwide by evaluations by experienced medical practitioners and adding brief computerised

neuropsychology tests and the SCAT3- tool. These tests add an element of objectivity to the RTP protocol (McCrory *et al.* 2013).

Testing these athletes when they are asymptomatic with Immediate Post-Concussive Assessment and Cognitive Testing (ImPACT), CogSport or Automated Neuropsychological Assessment Metrics (ANAM) tests is probably more useful for comparing a pre-season baseline score with a post-concussion score (McCrory 2004). A recent review highlights the possibility of doing away with baseline testing altogether and incorporating a post-injury neuropsychology test such as ImPACT or ANAM with matched normative data only (Echemendia, Iverson, McCrea *et al.* 2013; Schmidt, Register-Mihalik, Mihalik *et al.* 2012). The Zurich 2012 Consensus confirms that there is still insufficient evidence to recommend the use of baseline neuropsychological testing and normative data may be utilised (Schmidt *et al.* 2012).

The widely used ImPACT test has a sensitivity of 81.9% and specificity of 89.4% (Schatz, Pardini, Lovell *et al.* 2006) when added to a symptom checklist, but a single cognitive test is still inadequate to safely clear an athlete to RTP (Barlow *et al.* 2011; Resch *et al.* 2011).

The individual sensitivity of a test battery evaluating concussion symptoms (68.0%), ImPACT (79.2%) and postural stability (61.9%) increases to more than 90% when added together and administered within 24 hours of a concussion (Broglio, Macciocchi, Ferrara *et al.* 2007). The computerised neurocognitive tests require time to administer, expensive equipment and monthly subscriptions. Limited resources and availability of trained professionals to adequately administer and evaluate these tests also remain a challenge (Resch *et al.* 2011).

Serial neuropsychology tests may be helpful in the hands of experienced physicians who can incorporate the limitations of these tests to make informed decisions about RTP. One of the limitations of the tests is the learning or practice effect if these tests are done soon after the baseline, but alternative forms of the test or doing the test twice at baseline may reduce this effect (Collie *et al.* 2004). Regression towards the mean with test results at the extreme of the range will confound the results and could be addressed by using a control group (Collie *et al.* 2004).

2.8 SIDELINE TESTS

According to the 4th Consensus Statement additional tests like the RT_{Clin} may be useful in sideline concussion assessment (Eckner, Kutcher, Broglio *et al.* 2014; McCrory *et al.* 2013).

Testing response speed or reaction time has been shown to be a better predictor of cognitive function change, especially if serial performance is tested, rather than paper and pencil neuropsychology tests being administered (Collie, Maruff, McStephen *et al.* 2003). Prolongation of SRT is one of the most sensitive measurements of cognitive function, especially in the period following a concussion (Eckner *et al.* 2014; Collie *et al.* 2003).

It seems that specific cut-off scores of reaction time determined by ImPACT may even be predictive of poor or prolonged recovery if used together with a PCSS (Lau, Collins, Lovell *et al.* 2012).

2.8.1 Reaction time

Reaction time can be defined as the response time from the time a stimulus is given until the desired action is completed (Mackenzie 1998). Psychologists define three types of reaction times: a) SRT, that is, the reaction test has a singular stimulus and response; b) recognition reaction time, that is, multiple stimuli require one correct response and the distracting stimuli being ignored; and c) choice reaction time, where one response (out of multiple choices) must be given to a corresponding stimulus (Luce 1991).

Researchers have used reaction time for more than a century and a half. Schweickert (2012) refers to Donders, who first proposed a subtractive method for describing reaction time, as the sum of the time to complete all the serial processes (now called stages) involved, as far back as 1868. Using this method during an experiment of choice reaction time one needs only to subtract the SRT from the total reaction time to obtain the time taken for discrimination and choice (Schweickert 2012; Sternberg 1969).

Sternberg (1969) proposes the additive factor method: Reaction time also involves the sum of the duration of serial stages, but by changing a task slightly it adds factors to the experiment and these factors may prolong different stages. If they prolong reaction time they are additive factors to serial stages, but if they are not additive they interact and probably affect the same stage and invalidate the experiment (Schweickert 2012).

These stages may include: a) conversion of the stimulus by the sensory organ; b) stimulus transmission to the brain; c) perceptual recognition of the stimulus; d) choice of the response; e) transmission of the response signal to the muscles; and f) activation of the muscles (Welford 1988). Reaction time consists of many complex interactions, but its

predictability enables investigators to study cognitive function by measuring the time it takes to perform a task (Niemi & Näätänen 1981).

A multitude of factors have been suggested to influence reaction time:

- The type of stimulus, with sound being faster than light (Johnson, McClearn, Yuen *et al.* 1985);
- Stimulus intensity: the greater the intensity, the greater SRT (Froeberg 1907);
- Arousal: arousal increases SRT (VaezMousavi, Barry, Clarke *et al.* 2009);
- Age: SRT is slowed due to motor output slowing (Woods, Wyma, Yund *et al.* 2015);
- Gender: though males were not found to be faster than females (Woods *et al.* 2015);
- Dexterity: Left-handed people are faster than right-handed people (Barthelemy & Boulinguez 2001);
- Lateral visual field stimuli from contra lateral side to the responding hand were faster (Woods *et al.* 2015)
- Time: SRT was faster after three weeks of practice (Ando, Noriyuki & Shingo 2002);
- Fatigue decreases response times (Cote, Milner Smith *et al.* 2009);
- Distraction decreases reaction time (Trimmel & Poelzl 2006);
- Personality traits affect reaction time (people with neuroticism trait have slower response times) (Robinson & Tamir 2005);
- Attention deficit hyperactivity disorder (ADHD): sufferers have slower reaction times when not medicated (Littleton, Schmidt, Register-Mihalik *et al.* 2015);
- Stimulants, such as methylphenidate, improve reaction time (Littleton *et al.* 2015), as does caffeine (Durlach, Edmunds, Howard *et al.* 2002);
- Fitness, as fitter individuals are faster (Nakamoto & Mori 2008);
- Education has no significant effect (Woods *et al.* 2015); and
- Brain injury slows reaction time (Collie *et al.* 2006; Eckner *et al.* 2014).

SRT has proven to be a sensitive test for demonstrating cognitive impairment and identifying SRC in 42% (Erlanger *et al.* 2001) and 43% of cases (Broglio *et al.* 2007). It has also been found that SRT may be prognostic, predicting prolonged recovery by using cut-off values (Lau *et al.* 2012). These authors noted that SRT's predictive values were not statistically significant and they call for future studies with larger sample sizes to support its predictive use (Lau *et al.* 2012).

Erlanger *et al.* (2001) found persistent impairment with their SRT in 19% of asymptomatic athletes. This suggests SRT's ability to track cognitive dysfunction, even after full resolution of symptoms.

2.8.2 Simple clinical reaction time test

Eckner *et al.* (2014) propose a simple clinical test of reaction time (RT_{Clin}) for resource-limited areas, where computer-based neuropsychological tests are unavailable. The authors report a sensitivity of 75%, specificity of 68%, and reliable change confidence interval of 65% (Eckner *et al.* 2014).

These authors compared baseline and post-concussion SRT using a visuomotor test involving a falling measuring stick to calculate reaction time. The greatest advantage of this test lies in its simplicity and low cost (Eckner *et al.* 2014). Eckner *et al.* (2011) reported the added benefit of performance feedback and motivation over computerised reaction time measures. This feedback may lead to more accurate results with less variability than found in computerised tests (Eckner *et al.* 2011).

Testing SRT limits the practice effect; this means it is repeatable with excellent test-retest reliability (Eckner *et al.* 2011; Collie *et al.* 2001) and may possibly be suitable for cognitive recovery tracking (Erlanger *et al.* 2001). Simple reaction time may be measured to a thousandths of a second, which ensures the detection of even mild cognitive impairment (Collie *et al.* 2003). The combination of accuracy and repeatability may ensure safer RTP decisions, even in asymptomatic athletes (Erlanger *et al.* 2001).

2.9 CONCLUSION

In resource-limited areas neurophysiologists and computerised neuropsychology tests are not available. In this environment the experienced clinician who is required to treat SRC needs more objective tools to help diagnose, evaluate and clear athletes for RTP protocols.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter the methodology of the study is presented. The aim of the study was to determine what value a clinical reaction time test (RT_{Clin}) has as an outcome-based measurement tool when used as part of a comprehensive post-concussion assessment battery, and to describe the post-concussion recovery curve using a simple clinical reaction time test (RT_{Clin}).

3.2 DESIGN OF THE STUDY

This was a prospective study of a cohort of non-professional collegiate rugby union players who sustained concussion during one season.

3.2.1 Target population

The target population was collegiate rugby union players of the Stellenbosch Rugby Football Club (SRFC) diagnosed with concussion in one season. The SRFC consists of 53 teams that play at different levels of competition. In 2014 a total of 1 166 players registered to participate in five league fixtures. During the season 46 players, exposed to a total of 9 750 match-player hours, were concussed.

Concussed players were assessed on field by trained rugby first aiders. Players were managed according to the Consensus Statement on Concussion in Sport (McCrory *et al.* 2013) and all suspected or concussed players were immediately removed from the field and taken to the medical room for further assessment. Players with a suspected concussion or actual concussion were not allowed to return to play on the same day. Further medical management included a medical practitioner obtaining a history, and clinical examination by means of the SAC tool. Management was dictated by identifying warning signs, followed by giving concussion advice, discharge with adequate supervision at home and follow-up arranged in 24-48 hours for the first study evaluation.

a) Inclusion criteria for selection of study participants
Study participants adhered to the following inclusion criteria (Evaluation 1 (E1), see Appendix A):

- Registered Stellenbosch University rugby player;
- Concussion as defined by 2012 Zurich Consensus Statement on Concussion in sport; and
- Injured in the period 1 January 2014 to 31 October 2014.

b) Exclusion criteria for selection of study participants
Players were excluded when they met these criteria (Evaluation 1 (E1) see Appendix A):

- Non-registered players;
- Upper limb injury of the dominant side;
- Concussion in the preceding six months;
- On medication (anti-epileptics, sedatives and opioids); and
- History of ADHD or neurological disorders, such as seizures, migraine, brain surgery or learning disabilities.

3.2.2 Sample population

A total of 1 161 rugby players were registered at Stellenbosch Rugby Club for the study period 1 January 2014 to 31 October 2014. The season entailed 243 matches of 60 minutes each (30 + 30 minutes) and 123 matches of 80 minutes each (40 + 40 minutes), giving a total of 9 750 match-player hours.

In total 46 concussions were recorded during the study period.

Excluded cases comprised three players, due to incomplete forms or data. A total of five cases were excluded due to exclusion criteria: three cases has suffered concussion in the preceding six months, one case had been diagnosed with ADHD and was on methylphenidate, and one case had been diagnosed with bipolar mood disorder and was on lithium.

A total of 38 players were included in the study. Their ages ranged from 18 to 33 years of age, with a median age of 21 years.

3.3 PROCEDURE

- All athletes who met the inclusion criteria and none of the criteria for exclusion were evaluated within 24-72 hours post injury (E-1) with SCAT3 and an RT_{Clin} test.
- The players were evaluated weekly (E-X, see Appendix B) with SCAT3 and RT_{Clin} until they were asymptomatic.
- Once the injured athlete was asymptomatic (E-Asym see Appendix C), he was evaluated clinically again with SCAT3 and RT_{Clin}, plus:

  A. If an athlete was asymptomatic and met all requirements for RTP at E-Asym, he then underwent a CogState Sport computerised neuropsychological test (when clinically indicated) and only then was he cleared to start the RTP protocol.
  B. If an athlete was asymptomatic but did not yet meet RTP requirements at E-Asym, he was followed up until RTP could be initiated. At this time a CogState Sport evaluation was done (when clinically indicated).

- All tests were done as per the standard concussion protocol (as described above) at Campus Health Services of Stellenbosch University.
- The additional RT_{Clin} was performed by one trained clinical nurse practitioner.

3.4 MEASUREMENT

3.4.1 Measurement instruments

a) Standardized Assessment of Concussion (SAC)
   SAC is a mental status assessment that comprises orientation questions, immediate memory questions and questions testing concentration (Guskiewicz *et al.* 2013).
b) Sport Concussion Assessment Tool 3 (SCAT3)
   SCAT3 is a clinical battery test consisting of injury severity assessment (GCS), orientation and memory score (Maddocks questions), physical sign score, symptom assessment (PCSS), mental status assessment (SAC) and balance testing (MBESS) (Guskiewicz *et al.* 2013).
c) SCAT Score
   The total score is the sum of the individual SCAT scores: PCSS is a positive score to a maximum of 132, SAC is an error score (negative) to a maximum of 20, MBESS is a positive score to a maximum of 30, Coordination examination is a negative score to a

maximum of 1 and SAC delayed recall is a negative score to a maximum of 5. The lowest total score is 0 and the maximum score is 178.

d) CogState Sport computerised neuropsychological test

This is a computer test lasting approximately 20 minutes, and which tests neurocognitive function in four areas: SRT, complex reaction time, working memory test and learning memory task (Randolph *et al.* 2005). The test is submitted and results are received online. If the athlete completed a baseline test the results will include and compare post-injury results with his baseline.

e) Simple Reaction Time: RT_{Clin}

RT_{Clin} consists of a weighted measuring stick. This stick is an 80 cm ruler, marked in 0.5 cm increments, a small weight (standard ice hockey puck weighing 170 g) attached at the lower end. The athlete sits on a chair, with the dominant forearm resting on a desk and the hand positioned over the edge. The stick is suspended vertically between the thumb and index fingers. The fingers are held wide enough to avoid contact with the weight. The examiner randomly drops the stick after two to five second intervals, a total of 10 times. The first two tests are used as practice and the next eight attempts are recorded. The reaction time (t in seconds) is measured using the distance (d in metres) that the ruler fell, where $d = 0.5\ gt^2$ and $g = 9.8\ m/s^2$ (free-falling object under the influence of gravity). Simplified as $RT_{Clin} = 1000 \times \sqrt{2} \times d\ (cm)/980$ (recorded in milliseconds). The mean of the eight tests is used as the clinical reaction time (Eckner *et al.* 2013).

3.4.2 Collection of data

Data were recorded on data collection sheets: Evaluation-1 (E-1) was the first evaluation performed 24 to 72 hours post injury, Evaluation-X (E-X) were evaluations done weekly and Evaluation-Asymptomatic (E-Asym) was done when the athlete became asymptomatic.

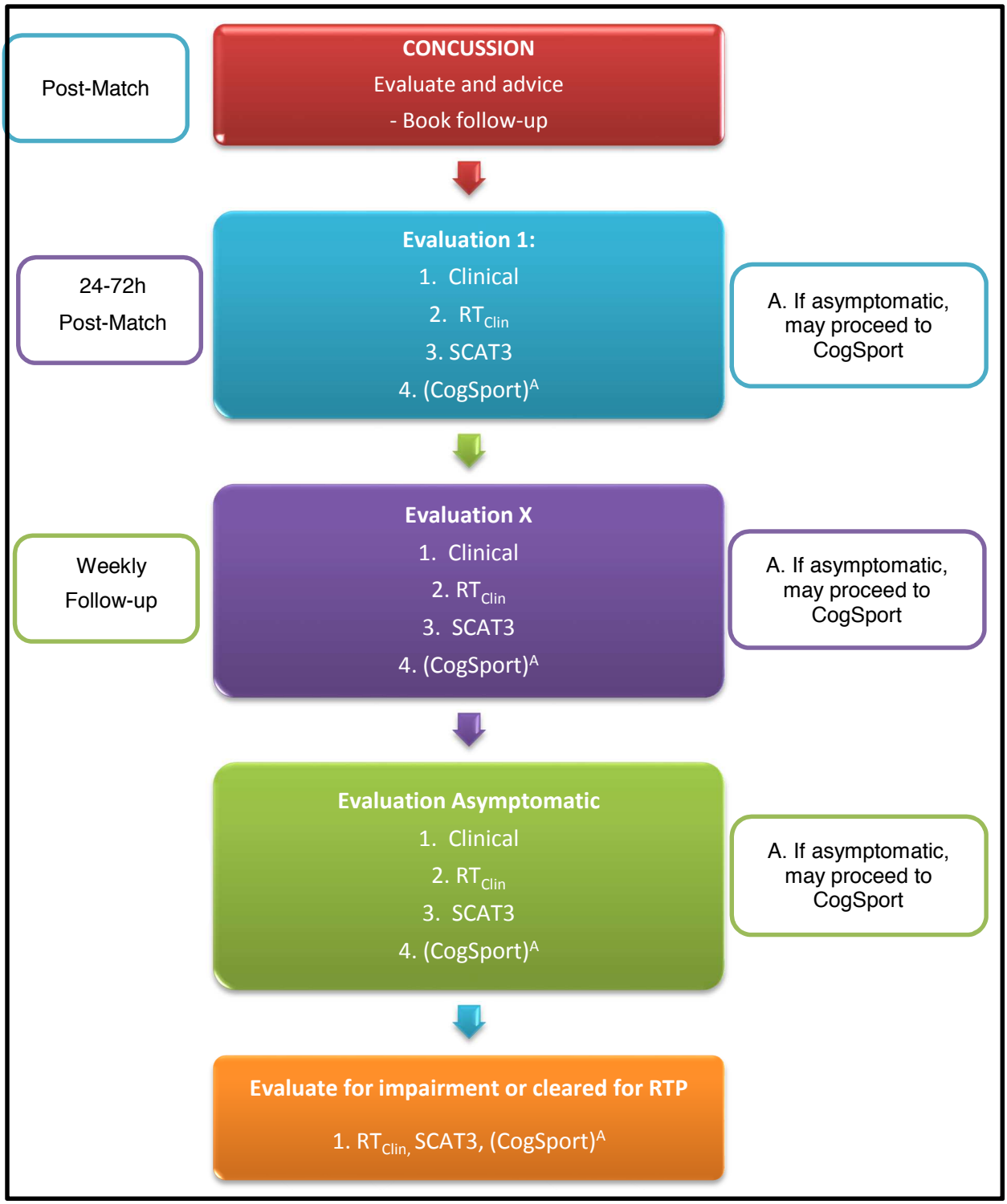


FIGURE 3.1: SCHEMATIC REPRESENTATION OF DATA COLLECTION

3.4.3 Pilot study

A pilot study was conducted after ethics approval had been obtained. A pilot study was conducted with 12 athletes with concussion. They were identified and tested according to the study design, the data were reviewed and the following changes were made to the study design:

a) Simplification of evaluation sheet data collection: The RT_{Clin} form was completed by the nurse practitioner and recorded on RT_{Clin} form, and the original SCAT3-form was attached. The main researcher captured SCAT3 data on evaluation sheets at weekly intervals thereafter.
b) Evaluations ended with completion of E-Asym and students were cleared to start RTP. The athletes were unwilling to return for a further two RT_{Clin} evaluations after they had been cleared to start the RTP protocol.
c) The first study aim was changed to compare RT_{Clin} with SCAT3 Score, instead of the neurocognitive computer test CogState Sport. This reflects the adoption of SCAT3 as the cornerstone of evaluation of concussion at SRFC. Only one case in the study period was evaluated with a CogState Sport.

3.4.4 Measurement errors

Random errors in both inter- and intra-observer variations were minimised by utilising only one trained nurse practitioner. The researchers were not blinded to which athletes were concussed, but with the reaction tests recording changes at thousandths of a second; this most likely did not make a difference. Regression towards the mean for extreme test results may always be considered a limiting factor (Collie *et al.* 2004). Systematic errors (bias) may have occurred when athletes bypassed the medical centre (those who were transported directly to hospital or who only sought medical attention later), when concussion not identified on the field or not enrolled in the study by other nurse practitioners.

3.5 DATA ANALYSIS

Data analysis was done by the Department of Biostatistics, University of the Free State. Categorical data were analysed using frequencies and percentages. Numerical data were analysed using means, standard deviations or percentiles. A p value of less than 5% ($p < 0.05$) indicated statistical significance.

3.6 IMPLEMENTATION OF FINDINGS

Findings were used to evaluate the SRT test's utility in a sport concussion battery: post-injury assessment, recovery tracking and as a RTP protocol tool. These findings may influence the implementation of RT_{Clin} as part of a multifaceted concussion assessment battery, especially in a resource-limited setting.

3.7 ETHICAL ASPECTS

The research protocol was submitted to and approved by the Ethics Committee of the Faculty of Health Sciences, University of the Free State (REF NR: ECUFS 103/2013) (Appendix D).

Data collection took place Stellenbosch University and therefore the research protocol was also submitted to the director of the Centre for Human Performance Sciences at this university. Permission was also obtained from the senior director of Campus Health Service of Stellenbosch University. Permission was obtained from the director of Maties Sport (Appendix E).

Participation in the study was voluntary, and informed consent (Appendix F) was obtained from each participant at registration, before the season started. The database with the results was password protected and no personal detail was revealed.

CHAPTER 4

RESULTS

4.1 INTRODUCTION

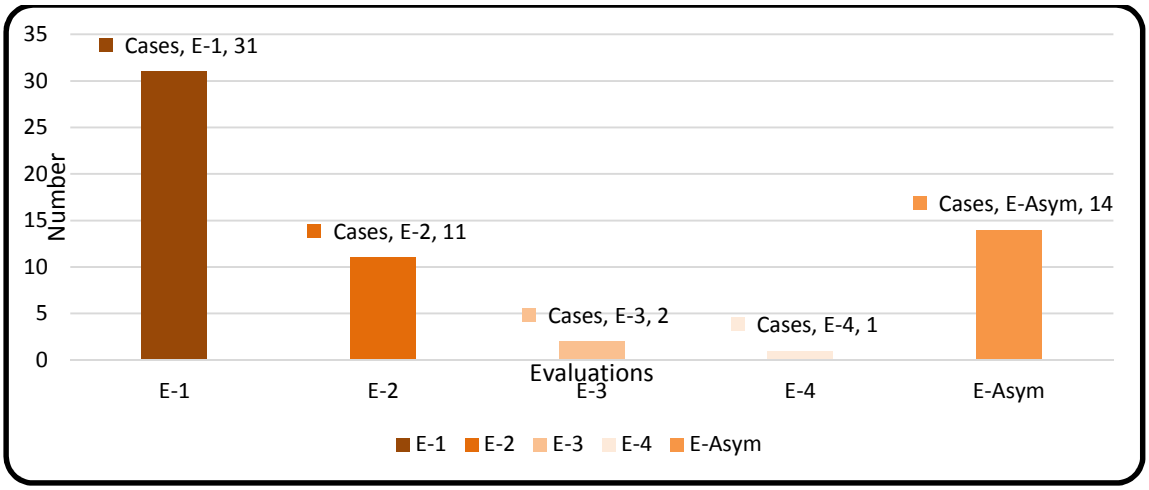
In this chapter the study population, demographics and post-concussion SCAT3 and RT_{Clin} data are presented for the first 72 hours after injury, with Evaluation 1 (E-1), weekly follow-up Evaluations 2, 3 and 4 (E-2, 3 and 4), and, lastly, when participants were asymptomatic, Evaluation Asymptomatic (E-Asym).

In the study period 1 January 2014 until 31 October 2014 a total of 1 161 players registered with the SRFC, and they recorded a total of 9 750 match-player hours during the season. The study recorded 46 concussions, with a season incidence at the club of 4.7 concussions per 1 000 match hours played.

Of the 46 athletes, 8 cases were excluded. Three cases had incomplete forms or data and five cases were excluded due to meeting exclusion criteria. Of these five cases three had had concussion in the preceding six months, one case reported ADHD and was on methylphenidate, and one case reported bipolar mood disorder and was on lithium.

A total of 38 players passed the inclusion criteria and were considered. Their ages ranged from 18 to 33 years of age, with a median age of 21 years.

Of these 38 players a total of 59 measurements were recorded. This consisted of 31 players completing Evaluation 1 (E-1), 11 players returned for Evaluation 2 (E-2) after the first week, 2 players completed Evaluation 3 (E-3) after the second week, 1 player completed Evaluation 4 (E-4) after week three and 14 players completed E-Asym when they became asymptomatic.



Evaluation 1 (31 Cases); Evaluation 2 (11 Cases); Evaluation 3 (2 Cases); Evaluation 4 (1 Case); Evaluation Asymptomatic (14 Cases); Total = 59

FIGURE 4.1: SUMMARY OF TYPES OF EVALUATIONS AND NUMBER OF CASES

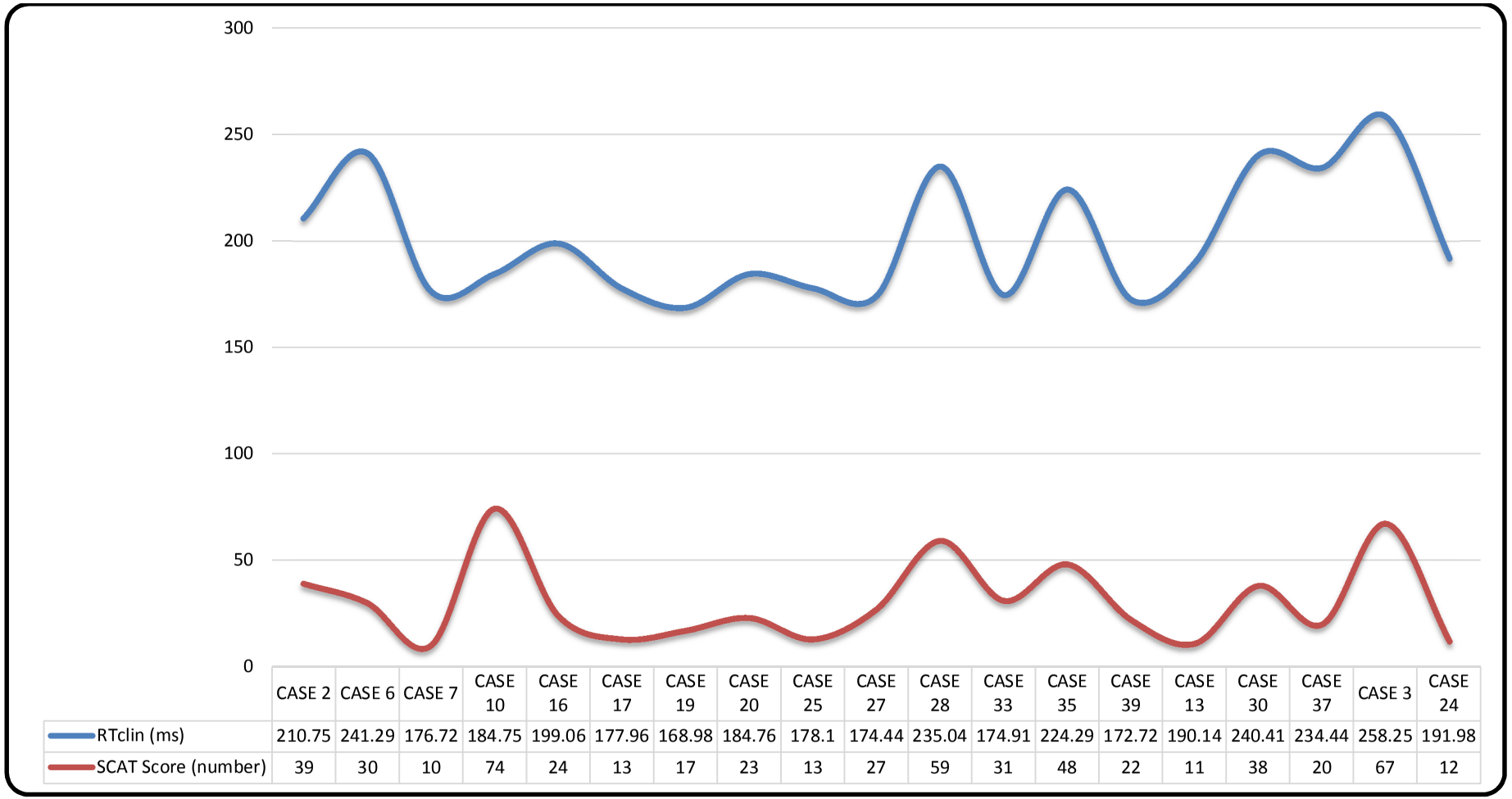
Of the total group, 31 athletes underwent E-1. This included 14 cases recorded in the first 24 hours post-concussion, 3 evaluated after 48 hours, and a further 2 after 72 hours with a total of 19, or 61%, evaluated within the 72 hour period.

After E-1 a further 11 athletes returned for Evaluation 2 (E-2) after one week.

The asymptomatic players numbered 14 and most (71%) became asymptomatic less than 10 days after concussion. The median to become asymptomatic was 7 days after injury, with a range of 34 days (1 to 35 days).

4.2 EVALUATION 1 WITHIN 72 HOURS

According to the study design 19 athletes were included within the first three days post-concussion, and their SCAT3, RT_{Clin} were recorded and compared.



	CASE 2	CASE 6	CASE 7	CASE 10	CASE 16	CASE 17	CASE 19	CASE 20	CASE 25	CASE 27	CASE 28	CASE 33	CASE 35	CASE 39	CASE 13	CASE 30	CASE 37	CASE 3	CASE 24
RTclin (ms)	210.75	241.29	176.72	184.75	199.06	177.96	168.98	184.76	178.1	174.44	235.04	174.91	224.29	172.72	190.14	240.41	234.44	258.25	191.98
SCAT Score (number)	39	30	10	74	24	13	17	23	13	27	59	31	48	22	11	38	20	67	12

FIGURE 4.2: COMPARISON OF SCAT3 AND RT_{CLIN} (MS) WITHIN 72 HOURS (n = 19)

The data did not follow a normal distribution curve and therefore medians and quartiles of 25% and 75% were used to summarise the data.

TABLE 4.1: SUMMARY OF SCAT3 SCORE (NUMBER) AND RT_{CLIN} (MS) MEAN EVALUATIONS WITHIN 3 DAYS

VARIABLE	n	MEDIAN	LOWER QUARTILE	UPPER QUARTILE	MINIMUM	MAXIMUM
Days	19	1.00	1.00	2.00	1.00	3.00
SCAT3	19	24.00	13.00	39.00	10.00	74.00
RTMean	19	190.14	176.72	234.44	168.98	258.25

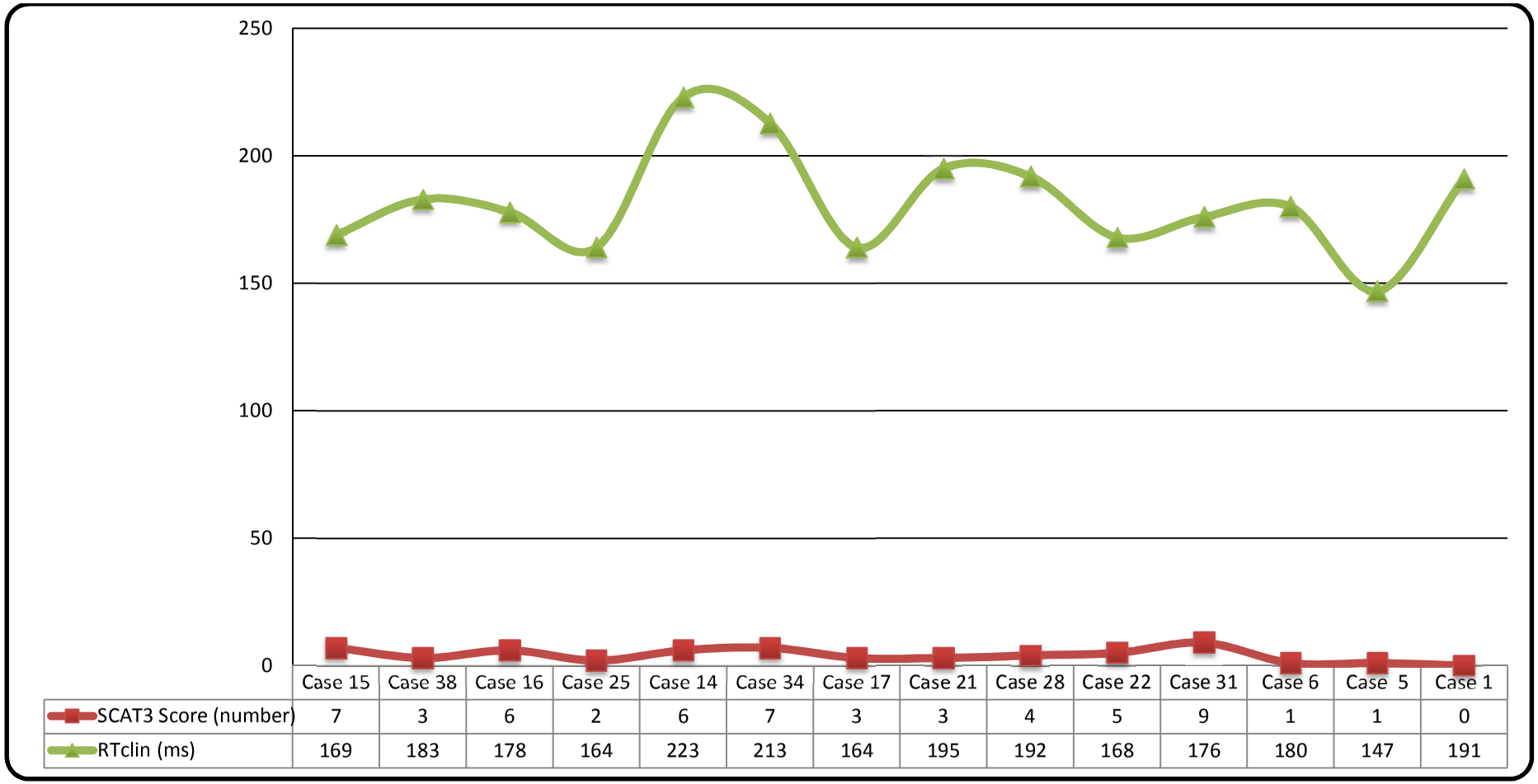
Days – Days after concussion on Evaluation 1 (E-1)
SCAT3 – SCAT3 on E-1; RTMean – RT_{Clin} mean values (ms) on E-1.

The Spearman correlation between SCAT3 and RT_{Clin} within the first three days (E-1) showed a moderate positive correlation of 0.47 ($p = 0.04$).

4.3 COMPARISON OF SCAT3 AND RT_{Clin} WHEN ASYMPTOMATIC

A total of 14 athletes completed E-Asym, and the data were recorded when they became asymptomatic.

The cases presented on Days 1 to 35 post injury, with the median becoming asymptomatic on Day 7.



	Case 15	Case 38	Case 16	Case 25	Case 14	Case 34	Case 17	Case 21	Case 28	Case 22	Case 31	Case 6	Case 5	Case 1
SCAT3 Score (number)	7	3	6	2	6	7	3	3	4	5	9	1	1	0
RTclin (ms)	169	183	178	164	223	213	164	195	192	168	176	180	147	191

FIGURE 4.3: COMPARISON OF SCAT3 SCORE AND RT_{CLIN} (MS) ASYMPTOMATIC CASES (E-Asym) (n = 14)

The data did not follow a normal distribution curve and therefore medians and quartiles of 25% and 75% were used to summarise the data.

TABLE 4.2: SUMMARY OF SCAT3 SCORE (NUMBER) AND RT_{CLIN} (MS) MEAN EVALUATIONS WHEN ASYMPTOMATIC

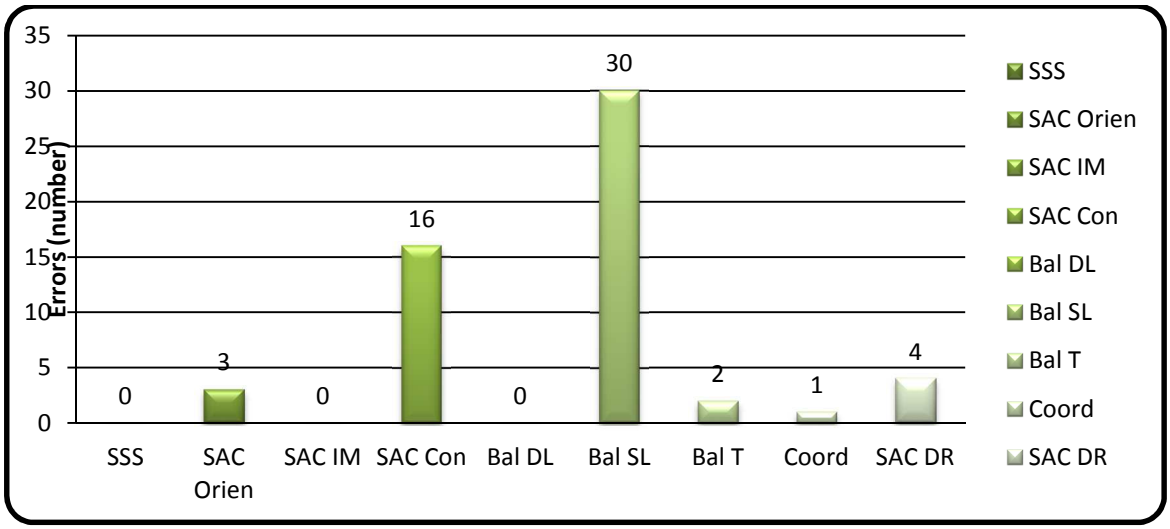
VARIABLE	n	MEDIAN	LOWER QUARTILE	UPPER QUARTILE	MINIMUM	MAXIMUM
Days	14	7.00	5.00	16.00	1.00	35.00
SCAT3	14	3.50	2.00	6.00	0	9.00
RTMean	14	179.33	168.64	192.60	147.52	223.34

Days – Days after concussion until asymptomatic
SCAT3 – SCAT3 on Evaluation Asymptomatic (E-Asym); RTMean – RT_{Clin} mean values (ms) on E-Asym

The Spearman correlation between SCAT3 and RT_{Clin} when the athletes were asymptomatic showed a poor correlation of 0.21 (p = 0.46). This is due to the low variation between the values of SCAT3 and RT_{Clin} when their scores became asymptomatic.

The E-Asym was completed when the athlete was evaluated for medical clearance and possible initiation of the RTP protocol. The athletes had, subjectively, no more symptoms but 13 (93%) objectively still revealed errors during the SCAT3 exam.

The individual scores for the SCAT3 when asymptomatic (Symptom Severity Score = 0) still showed the most errors with the Balance single leg stance (median 2 errors) followed by the SAC Concentration (median 1 error); only the SAC Immediate Memory and Balance double leg stance showed no errors.



SSS – Symptom severity score; SAC Orien - SAC orientation; SAC IM - SAC immediate memory; SAC Con – SAC concentration; Bal DL – Balance double leg; Bal SL – Balance single leg; Bal T – Balance tandem; Coord – Coordination; SAC and DR – SAC Delayed recall

FIGURE 4.4: SCAT3 INDIVIDUAL TEST ERRORS WHEN ASYMPTOMATIC (n = 14)

4.4 COMPARISON OF THE E-1 AND E-ASYM

As expected, evaluations cone within the first three days post-concussion showed the largest impairment of cognitive function and impairment was lowest during the asymptomatic examinations.

Considering the two groups' SCAT3 of E-1 and E-Asym, the scores show a significant difference of $p < 0.01$ (Mann-Whitney test). The RT_{Clin} difference between E-1 and E-Asym is almost significant, at $p < 0.07$ (Mann-Whitney test).

4.5 RECOVERY TRACKING USING SCAT3 AND RT_{Clin}

Out of the 19 athletes from E-1 within 72 hours, 5 cases were tracked and until they became asymptomatic. The SCAT3 and RT_{Clin} were used to track their recovery over time.

The data did not follow a normal distribution curve and therefore medians and quartiles of 25% and 75% were used to summarise the data. The SCATDiff and RTDiff values are negative due to the fact that their values decrease over time.

TABLE 4.3: TRACKING RECOVERY WITH SCAT3 (NUMBER) AND RT_{CLIN} (MS) UNTIL ASYMPTOMATIC

VARIABLE	n	MEDIAN	LOWER QUARTILE	UPPER QUARTILE	MINIMUM	MAXIMUM
DaysDiff	5	6.00	4.00	7.00	4.00	18.00
RT1	5	199.06	178.10	235.04	177.96	241.29
RT2	5	178.19	164.81	180.47	164.62	192.60
SCAT3a	5	24.00	13.00	30.00	13.00	59.00
SCAT3b	5	3.00	2.00	4.00	1.00	6.00
SCATDiff	5	-18.00	-29.00	-11.00	-55.00	-10.00
RTDiff	5	-20.87	-42.44	-13.34	-60.83	-13.29

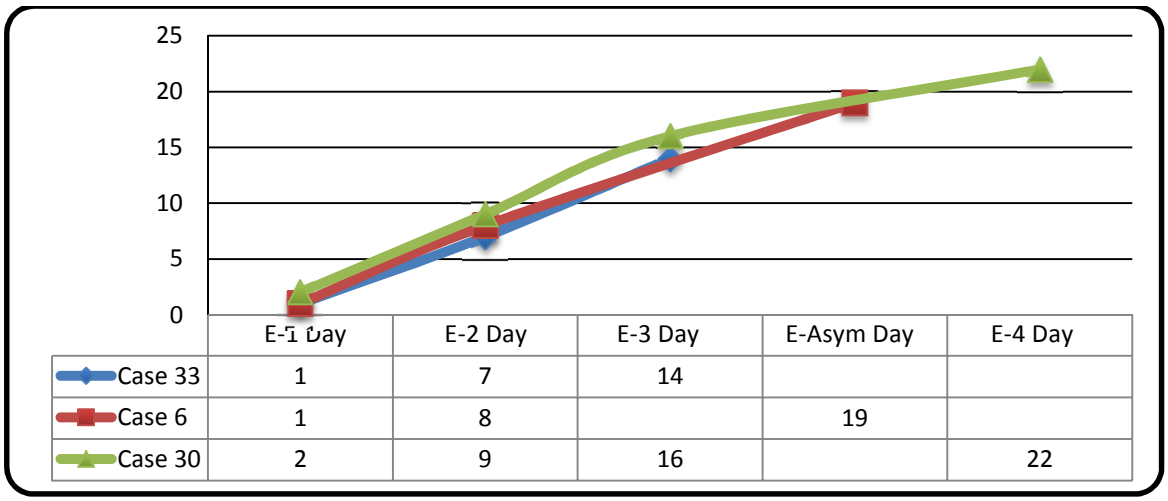
DaysDiff – Difference in days from E-1 to E-Asym; RT1 – RT_{Clin} (ms) at E-1; RT2 – RT_{Clin} (ms) at E-Asym; SCAT3a – SCAT3 at E-1; SCAT3b – SCAT3 at E-Asym; SCATDiff – Difference between SCAT3 at E-1 and at E-Asym; RTDiff – Difference between RT_{Clin} (ms) at E-1 and at E-Asym

The median recovery of these 5 cases was 6 days to become asymptomatic, but with a range of 4 to 18 days. The Spearman correlation between the changes of the SCAT3 and RT_{Clin} show a strong positive correlation over time of 0.80, but $p = 0.105$, and not statistically significant.

There is a negative correlation between the time passed in days (DaysDiff) until asymptomatic and the SCAT3 and RT_{Clin} recovery of -0.56 and -0.82 respectively, but this is not statistically significant ($p > 0.05$).

4.6 PRESENTATION OF PERSISTENT CONCUSSION CASES

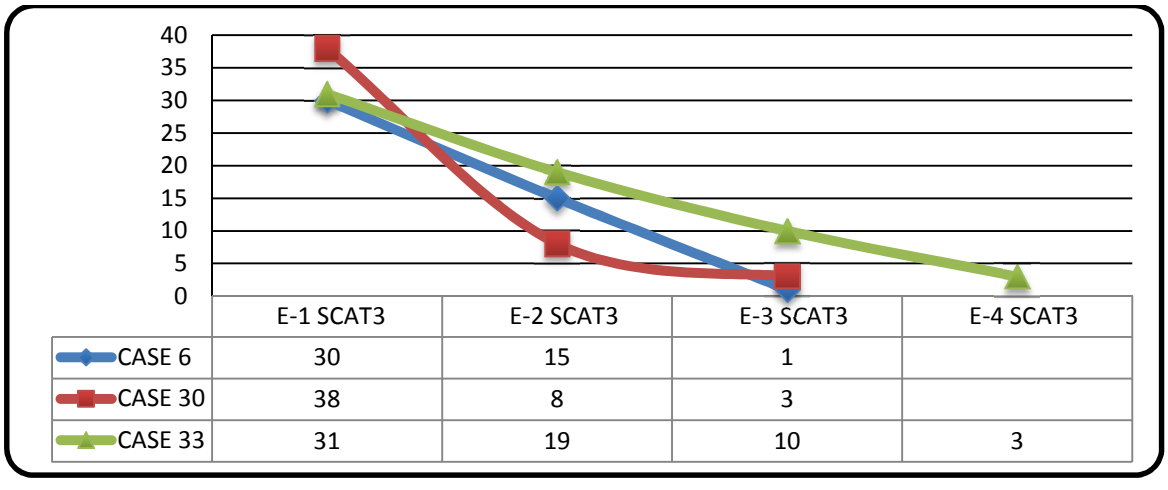
Three cases presented for more than three evaluations: two players completed E-1 to E-3, one of these players completed four evaluations, E-1 to E-4, and one player completed E-1, E-2 and E-Asym. All three cases show persistent symptoms beyond 14 days.



	E-1 Day	E-2 Day	E-3 Day	E-Asym Day	E-4 Day
Case 33	1	7	14		
Case 6	1	8		19	
Case 30	2	9	16		22

FIGURE 4.5: EVALUATION DAYS FOR CASE STUDY: CASE 33 (E-1 TO E-3), CASE 30 (E-1 TO 4) AND CASE 6 (E-1, E2 & E-ASYM) (n = 3)

Case 6 became asymptomatic on Day 19, but cases 30 and 33 remained symptomatic even after Day 16 and Day 22 respectively. Persistent symptoms after Day 10 are only seen in 10 to 15% of cases (McCrory *et al.* 2013).

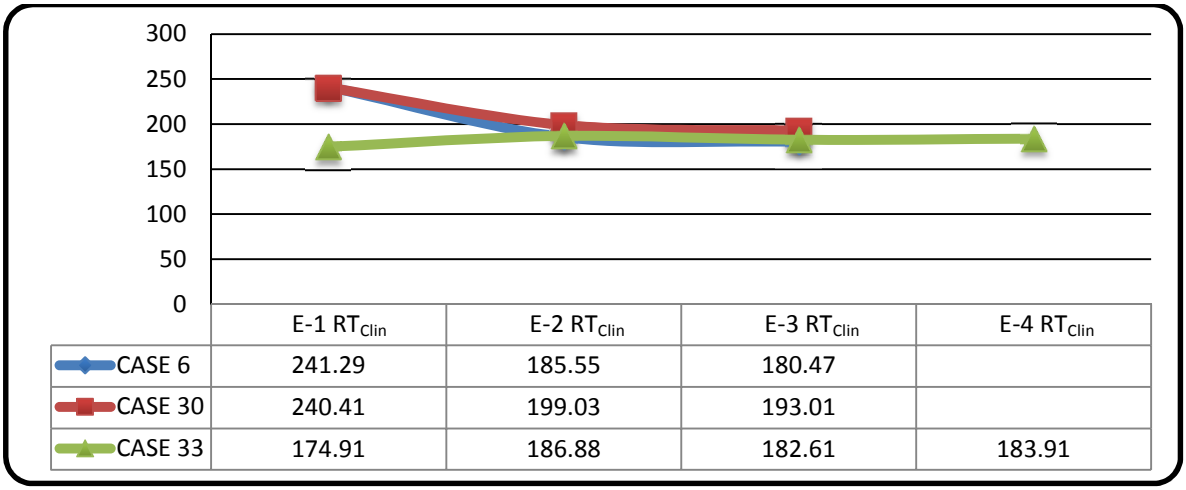


	E-1 SCAT3	E-2 SCAT3	E-3 SCAT3	E-4 SCAT3
CASE 6	30	15	1	
CASE 30	38	8	3	
CASE 33	31	19	10	3

FIGURE 4.6: SCAT3 SCORE RECOVERY OVER TIME: CASES 6, 30 AND 33

Cases 6 and 30 show a linear recovery trend in both SCAT3 and RT_{Clin} scores, but case 33 showed a linear recovery in SCAT3 but almost unchanged RT_{Clin} tests. All 3 cases presented within 72 hours after injury, all three SCAT3 Scores > 30 at E-1, both cases 6 and 30 had RT_{Clin} > 240 ms at E-1, but RT_{Clin} of case 33 was 175 ms.

A previous study proposed cut-offs for prediction of prolonged recovery as PCSS's migraine symptom cluster of 18 and cognitive cluster of 19 (37 total) in the first 72 hours (Lau *et al.* 2012). These authors combined these two symptom scores with ImPACT score cut-offs to predict 80% sensitivity of persistent concussion symptoms > 14 days (Lau *et al.* 2012). Further research with larger sample sizes may suggest the combination of SCAT3 Score and RT_{Clin} utility of predicting prolonged recovery.



	E-1 RT_{Clin}	E-2 RT_{Clin}	E-3 RT_{Clin}	E-4 RT_{Clin}
CASE 6	241.29	185.55	180.47	
CASE 30	240.41	199.03	193.01	
CASE 33	174.91	186.88	182.61	183.91

FIGURE 4.7: RT_{CLIN} (MS) RECOVERY OVER TIME: CASES 6, 30 AND 33

4.7 CONCLUSION

The introduction described the study population and reported the incidence of concussion at SRFC for the 2014 season. Next, a summary of the total evaluations included in the study was presented.

The athletes who presented within the first three days post-concussion were evaluated with SCAT3 and RT_{Clin}, and comparisons were summarised. The data showed a moderate positive correlation between SCAT3 and RT_{Clin} within the first 72 hours.

Next, a summary of the comparison between the RT_{Clin} and SCAT3 when the athletes were subjectively asymptomatic was presented, but there was poor correlation between SCAT3 and RT_{Clin} of asymptomatic athletes. The persistent cognitive impairment after the athletes

become asymptomatic was an interesting finding and showed, specifically, that the Single leg balance test produced findings pointing to persistent impairment.

The symptomatic athletes evaluated by E-1 were reviewed together with the athletes when the athletes became asymptomatic with E-Asym. This review showed the highest impairment during E-1 and the lowest during E-Asym.

The recovery over time of asymptomatic athletes was tracked using the SCAT3 and RT_{Clin}, and the findings summarised. The changes in the SCAT3 and RT_{Clin} show a strong positive correlation over time.

Finally, a case presentation was made of the three cases whose symptoms persisted >10 days after injury. It may be possible, with further research, to utilise the SCAT3 Score with RT_{Clin} as tools to predict prolonged recovery.

CHAPTER 5

DISCUSSION

5.1 INTRODUCTION

The complex management of concussion compels physicians to utilise a multifaceted assessment battery of tests, as no single test (Grant *et al.* 2014; Barlow *et al.* 2011; Resch *et al.* 2011; Riemann & Guskiewicz 2000) is able to give a comprehensive picture of a concussed athlete. This study examined the feasibility of incorporating the novel, simple, clinical sideline test, RT_{Clin}, into a concussion battery assessment.

The study's primary aim was to compare RT_{Clin} with the SCAT3, and a secondary aim was to describe the recovery from concussion by using both tests.

Concussed collegiate athletes from SRFC were studied over one season and SCAT3 and RT_{Clin} test data were collected at each evaluation. The athletes were identified on the field, treated and injury management was initiated utilising the Consensus Statement on Concussion in Sport (McCrory *et al.* 2013) guidelines. These athletes were followed up within 72 hours for the first evaluation, and weekly thereafter, until they were deemed asymptomatic.

Each athlete was examined with SCAT3 and RT_{Clin}, and data were recorded on data forms: Evaluation-1 (E-1), Evaluation-2 (E-2), Evaluation-3 (E-3), Evaluation-4 (E-4) and Evaluation-Asymptomatic (E-Asym).

The University of the Free State's Department of Biostatistics analysed the data, using frequencies and percentages to summarise the categorical data variables and means, standard deviations or percentiles the numerical data variables. A p-value of less than 5% ($p < 0.05$) indicated statistical significance.

5.2 RESULT OVERVIEW

In the study period from 1 January 2014 to 31 October 2014 a total of 1 161 players registered with the SRFC and played a total of 9 750 match hours. In the season 46 concussions were recorded, with a season incidence of 4.7 concussions per 1 000 game hours played. This incidence was slightly higher than that found by a previous study, which

showed the incidence of concussion among college rugby union players as 2.16 per 1 000 hours of game time (Kerr *et al.* 2008). At high school level concussion incidence is reported as 1.45 per 1 000 game hours (Junge *et al.* 2004) and 6.8 per 1 000 game hours played (Mc Fie *et al.* 2014). The reported incidences of concussion among professional players ranged from 4.1 per 1 000 game hours (Kemp *et al.* 2008) to 8.9 per 1 000 game hours (Cross *et al.* 2015).

Underreporting of concussion is a worldwide phenomenon and estimates are higher than 50% in the USA (Harmon *et al.* 2013). Two studies found more than 52% of players that did not report the injury (Fraas *et al.* 2014; McCrea *et al.* 2004). The most common reasons given for underreporting were underestimating the severity of the injury, and secondly, not wanting to miss part of the game (Fraas *et al.* 2014). Direct supervision by researchers was shown to increase the reporting of concussion (Matsui 2009), and increased reporting from 8.7% to 18.4% among high school players (Roux *et al.* 1987). Sye *et al.* (2006) researched the self-reported concussion incidence in one high school competition (at first team level) and found that more than 62% of players admitted to the injury, but only 22% had medical clearance after the injury to RTP.

The current study's incidence is double the previous reported study for USA collegiate rugby union (Kerr *et al.* 2008). This may be due to the fact that, the current study had a total of 366 games, and 66% were at amateur level and 34% at club or semi-professional level. This meant that only two thirds of the current study population were collegiate amateurs with a mean age of 21. The game time for amateur matches was 60 minutes, which meant amateurs played shorter games, at a reduced intensity compared to club players (Bleakley *et al.* 2011; Roux *et al.* 1987).

Underreporting is known to occur. Factors contributing to underreporting may be misdiagnosis and self-management, with the latter the player bypasses the medical centre. Without direct, experienced medical supervision, concussions may be missed (Roux *et al.* 1987); this leads to lower incidence figures, especially for subtle cognitive dysfunctions.

Of the 46 concussed athletes identified, 8 were excluded and 38 were included for the study, and 59 measurements obtained. Athletes who returned for the first evaluation E-1 within 72 hours numbered 19 (50%) of the total and 14 (37%) completed E-Asym.

Factors causing poor compliance to the study design probably included lack of motivation, lack of knowledge, failure to identify all concussed athletes, failing to phone or send reminders for players to report for follow-up, and study design deficiencies.

This was a voluntary study and the athletes were reluctant to return for frequent follow-up evaluations. This was evident even after the pilot study, as no athletes returned for the two additional RT_{Clin} tests after they became asymptomatic (original study design). Previous studies have shown that even young adolescents (10-13 years) can be compliant, even with complicated unsupervised protocols, but financial reimbursement for tasks completed was shown to be very important (Lovinsky-desir *et al.* 2014). A full academic programme may prevent some athletes from making time for evaluations; most are aware that medical clearance is a requirement for RTP, but some decided to stop playing for the season.

Other forms of motivation could be employed by adopting a more collaborative approach and organising small informal meetings for each residence before the season. The Participatory Research and Action or Action Research approach was implemented with positive results, even in research areas aiming to intervene when cognitive impairment drug abuse was involved (Othieno *et al.* 2012). This approach aims to be collaborative in nature; with active participation encouraged before the season with the explicit aim of helping injured athletes recover faster and safely from concussion.

The development of a more accurate system for identifying all concussed athletes should be a priority. This researcher acknowledges that phone calls the next day may have improved follow-up compliance.

The study design did not incorporate the Consolidated Standards of Reporting Trials (CONSORT) guidelines (Kehoe *et al.* 2009). These guidelines would have improved tracking and follow-up of participants during the study period. There was no reason to believe that the study participants would remain compliant for the duration of the study period, especially with the study design requiring a change in their normal behaviour (Kehoe *et al.* 2009). The fact that the athletes had to return for frequent evaluations, to make appointments that suited the medical staff and thereby disrupt their normal routine contributed to low compliance (Matsui 2009).

5.3 EVALUATION 1 WITHIN 72 HOURS

Our null hypothesis stated that the RT_{Clin} showed no correlation to the SCAT3 Score.

In our study the SCAT3 Score and RT_{Clin} taken at the first evaluation, 72 hours after a concussion, did show a moderately positive correlation of 0.47 (Spearman test). This correlation was statistically significant, with $p = 0.04$.

The pilot study of Eckner *et al.* (2010) compared the RT_{Clin} with the SRT of the computerised test CogSport, and found a moderately positive 0.45 correlation, with $p < 0.001$ (Pearson test) at baseline. This preliminary study by Eckner *et al.* (2010) showed RT_{Clin} to be a valid measurement of male athletes' baseline reaction time.

To test the test-retest reliability from one season to the next Eckner *et al.* (2011) also compared the RT_{Clin} and the SRT of CogSport. They found that both tests showed moderate positive correlations between the seasons (0.65 and 0.51 Intra-class Correlation Coefficients respectively).

Next, this research group investigated the diagnostic utility of RT_{Clin}, which was assessed by testing concussed athletes within 48 hours and matching them with a control group (Eckner *et al.* 2014). Together with baseline tests the RT_{Clin} showed a sensitivity of 75%, specificity of 68% and a reliable change confidence level of 65% (Eckner *et al.* 2014). All this research shows that RT_{Clin} is a valid, sensitive, specific concussion sideline test with good test-retest reliability.

The SAC from the original SCAT was evaluated by Barr & McCrea (2001). They found a 94% sensitivity and 76% specificity when athletes were tested immediately after concussion. The PCSS has a sensitivity of 68% as a standalone test after concussion (Guskiewicz *et al.* 2013). The MBESS has a high Intra-class Correlation Coefficient, of 0.93 to 0.96 (single leg and tandem stance on a hard surface) (Riemann *et al.* 1999). The sensitivity or diagnostic value identified only 33 to 66% of concussed athletes, with the American Academy of Neurology rating this test as "not precise" (sensitivity 0.34 to 0.64 and specificity 0.91) (Giza *et al.* 2013; McCrea *et al.* 2005). This is still considered a reliable test for postural stability within 48 hours after concussion (Riemann *et al.* 1999). There is insufficient evidence at present to recommend the SCAT3 Score, but each individual test has evidence to support its use (Guskiewicz *et al.* 2013).

The positive correlation between SCAT3 Score and RT_{Clin} may indicate its usefulness as diagnostic tool during the first evaluation < 72 hours after concussion, including as a sideline test. Parker *et al.* (2007) found SRT improved significantly from Day 2 to Day 5, and concussed athletes returned to their normalised values by Day 5. This is especially true for the symptomatic athletes, as asymptomatic athletes' SRT return to control values quickly (Collie *et al.* 2006).

The 4th Consensus Statement suggests the clinical reaction time tests as a possible additional sideline test to be administered 15 minutes after injury, but suggested more research before a recommendation is made (McCrory *et al.* 2013). The role of fatigue and stress should be noted, as highlighted by Bleiberg *et al.* (2004), who report the deterioration of simple reaction in both the concussed and control groups of military cadets from their baseline tests.

5.4 COMPARISON WHEN ASYMPTOMATIC

The next part of comparing the SCAT3 and RT_{Clin} is obtained during the asymptomatic evaluation. A total of 14 athletes presented for evaluation to start a RTP protocol when they became asymptomatic. The median athlete became asymptomatic after 7 days, with a range of 1 to 35 days.

The Spearman correlation between the SCAT3 and RT_{Clin} when players are asymptomatic was poor, with a value of 0.21 and $p = 0.46$. This may be explained best by the low variation between the SCAT3 and RT_{Clin}, as both values return to zero and normal respectively.

The athlete is deemed to be asymptomatic when the PCSS reached zero, but other cognitive impairments may persist for longer. De Beaumont *et al.* (2011) found pervasive impairment of postural control more than 9 months after their athletes' last concussion. Fazio *et al.* (2007) reports persistent cognitive impairment in asymptomatic concussed athletes compared to a control group, and the asymptomatic group did perform better on the computerized cognitive test than the symptomatic group.

Even the definition or timing of being asymptomatic is made more complex by the fact that, at baseline, men aged 17 to 32 had a mean value of 3.52, rising to 5.25 with a history of previous concussions (Shehata *et al.* 2009).

In clinical practice this means a subjective symptom score of 5 and lower may be defined as asymptomatic. In some athletes even higher scores could mean "asymptomatic", if these are known or baseline symptoms. It also implies clinicians should not rely on PCSS as a single test for diagnosing SRC, nor as a standalone test for evaluating recovery.

The current study found the most errors with the SCAT3 (when asymptomatic) with the balance single leg stance test (30 errors and a median of 2 errors). A previous study found normative values for single leg stance on a firm surface, non-dominant leg, to be 1.3 to 1.7

mean errors per 30 second test (Schneiders *et al.* 2010). This study's 2 error median score is comparable with these normative control values.

The SAC test showed the second-most persistent cognitive impairment (16 errors and a median of 1 error). A previous study by McCrea *et al.* (2005) also found neurocognitive impairment in 8% (BESS test) and 7% (SAC test) of asymptomatic athletes on Day 7 post-concussion.

In clinical practice this means that PCSS is a good screening test if used together with SAC, BESS and RT_{Clin}, but during recovery the latter three tests become more important for identifying persistent impairment in asymptomatic athletes.

5.5 COMPARISON OF THE FIRST WITH ASYMPTOMATIC EVALUATIONS

A comparison of the first evaluations with the last unfortunately includes athletes who did not complete both evaluations. A dropout rate of >20% reduces the strength of conclusions made from these comparisons.

The first evaluation recorded the highest SCAT3 Score, with a median of 24 and a range of 10 to 74, and the asymptomatic median score of 3.5 with a range of 0 to 9. The difference between these two evaluations is statistically significant, with $p < 0.01$ (Mann-Whitney test).

No research has yet proven the utility of the sum of the SCAT3 scores, only of the individual tests (Guskiewicz *et al.* 2013). This study does show a statistically significant difference between the early injury total score and the late total score. Further research is needed to evaluate fully the usefulness of a SCAT3 Score.

The first RT_{Clin} also showed the biggest impairment, with a median of 190 ms and range of 168 to 258 ms, and the recovery of the asymptomatic RT_{Clin} mean of 179 ms and range 147 to 223 ms. The Mann-Whitney test comes close to significance between the evaluations, with $p = 0.07$.

The high dropout rate reduces the strength of the comparison that can be made, but this is among the first studies to investigate RT_{Clin} beyond 48 hours. More research, with larger samples of participants are needed to validate the utility of RT_{Clin} after the 48 hours reported by Eckner *et al.* (2013).

5.6 RECOVERY TRACKING WITH THE SCAT3 AND RT_{Clin}

A secondary aim of the study was to track concussion recovery by using SCAT3 and RT_{Clin} and to draw comparisons from these findings. Of the 19 athletes presenting for their first evaluation within 72 hours, 5 (26%) cases were tracked until they became asymptomatic. This high dropout number includes athletes who did not consent to the research, who were asymptomatic at the first evaluation, incomplete follow-ups and also athletes with persistent cognitive impairment.

The mean time to recovery for these 5 cases was 6 days, with a range of 4 to 18 days. Compared to a previous study by Iverson *et al.* (2006), which found that amateur athletes mostly recovered from symptoms and cognitive impairment by Day 5 and the impairment resolved after 10 days post-concussion. These authors note that, when each athlete's score was examined individually, 37% still showed some impairment from baseline values after 10 days (Iverson *et al.* 2006).

The SCAT3 mean score was 24 during the first evaluation of this study, and it reduced to a mean of 3 when the players were declared asymptomatic; the mean difference between the two scores was 18. To date no published studies have evaluated the mean SCAT3 Scores as diagnostic or recovery tools (Guskiewicz *et al.* 2013) and further research is needed to evaluate this further.

Similarly, the RT_{Clin} mean score, prolonged to 199 ms at the first evaluation, recovered to a mean of 178 ms when players were asymptomatic, to give a mean difference of 20 ms. Unfortunately, to date no published data exist for RT_{Clin} as a recovery-tracking tool, but reaction time on composite scores (ImPACT test) showed a decrease to 720 ms on Day 1 post-concussion, and a recovery to 600 ms on Day 10, with a baseline of 580 ms (Iverson *et al.* 2006).

The Spearman test shows a strong correlation between the SCAT3 and RT_{Clin} recovery over time, of 0.80, but with $p = 0.105$. This is not statistically significant, but further research and larger samples may help to investigate this further.

There is a negative correlation between the time passed in days until asymptomatic and the SCAT3 and RT_{Clin} recovery, of -0.56 and -0.82 respectively, but this is not statistically significant ($p > 0.05$). Both these values are negative because days passed is a positive

value; the change in SCAT3 and RT_{Clin} indicate as negative values and over time they become more negative.

The RT_{Clin} recovery tracking of -0.82 shows a strong correlation, but it is not statistically significant. This data is promising, but further research and larger samples may help to investigate this further.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

The incidence of concussion in a contact sport such as rugby union is high. It ranges from 1.45 to 8.9 concussions per 1 000 match hours played (Cross *et al.* 2015; Mc Fie *et al.* 2014; Kemp *et al.* 2008; Kerr *et al.* 2008; Junge *et al.* 2004). The complexity of diagnosing, managing and treating SRC is summarised best by the statement, "If you've seen one concussion, you've seen one concussion" (Brainline 2012). Each concussed athlete must be managed on an individual basis and, similarly, each test has its advantages and limitations.

When it comes to treating concussion, the bar is set higher for clinicians working in resource-limited settings, in which neuropsychological testing is not seen as the sole basis on which SRC athletes' management and return to play decisions should be based but as an objective aid (McCrory *et al.* 2013). In the absence of a neuropsychologist and computerised neuropsychology tests the need for additional low-cost objective cognitive tests developed. The excellent work of Eckner *et al.* (2013) provided the opportunity to establish the RT_{Clin} test as a possible objective, low-cost and fast sideline cognitive test. In a low-resource environment the combination of a clinical assessment, SCAT3 and RT_{Clin} may provide a more objective test battery than the former two alone. This study aimed to provide additional evidence for the use of RT_{Clin} in a test battery for SRC assessment and recovery monitoring.

6.2 LIMITATIONS AND STRENGTHS

Limitations of the study included the high dropout rate of injured athletes who failed to complete the study. It is known that up to 50% of concussions go unreported, and athletes may bypass the medical centre, causing errors by systematic bias. The other reasons for underreporting may include failing to identify cognitive impairments beyond the more severe, self-management, bypassing of the medical centre and athletes not included by other nurse practitioners for testing.

The high dropout rate of concussed athletes was probably due to lack of motivation amongst this group of largely amateur collegiate rugby players. This was a voluntary study, it required

additional follow-up visits, which represented a change to players' normal routines, and they were not supervised directly by researchers. The physical symptoms of concussion may decrease motivation and compliance to the study design.

The strength of the study was the use and training of one nurse practitioner for all the RT_{Clin} tests. This reduced random errors in both inter- and intra-observer variations.

6.3 CONCLUSIONS AND RECOMMENDATIONS

Within the limitations of the research, the data did suggest there exists a moderate positive correlation between the RT_{Clin} test and the SCAT3 Score taken in the first 72 hours after a SRC. This correlation was statistically significant and gives further support to previous studies into the use of RT_{Clin} as a simple, cost- effective sideline test for administration directly after an SRC, or at the first evaluation within the first three days.

The data obtained from the asymptomatic evaluation shows a weak to low correlation when testing the athlete with RT_{Clin} or SCAT3. In a clinical setting the MBESS and SAC parts of the SCAT3 Score and the RT_{Clin} become more important for identifying the persistent cognitive impairment when athletes are asymptomatic. By definition, the PCSS becomes normalised when the athlete is asymptomatic and remains clinically useful at an initial stage.

This study confirms that the first evaluation, conducted within 72 hours, reported the highest level of cognitive impairment, with both tests showing a recovery trend towards normailised values. Both these tests show promise in tracking athletes from symptomatic to asymptomatic, and tracking cognitive recovery beyond the asymptomatic stage. Especially the RT_{Clin} data showed a strong negative correlation in tracking the cognitive recovery of concussed athletes. The SCAT3 Score only showed a moderate negative correlation, but this may be explained by the strengths and weaknesses of the various individual tests ability to track cognitive impairment after 72 hours.

In summary, this study supports the diagnostic use of RT_{Clin} and SCAT3 Score tests as early, sideline cognitive tests within the first 72 hours after concussion. It further shows the benefits and possible strengths of RT_{Clin} as a cognitive impairment tracking tool, after the athlete has become asymptomatic. Unfortunately, due to the low numbers and high dropout rate of participants, no strong recommendations can be made from the data, but further research involving larger study populations may confirm the utility of the RT_{Clin} as part of a post-concussion assessment battery.

CHAPTER 7

LESSONS LEARNED: PERSONAL EXPERIENCE

Reports that say that something hasn't happened are always interesting to me, because as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns -- the ones we don't know we don't know. And if one looks throughout the history of our country and other free countries, it is the latter category that tend to be the difficult ones.

- Donald Rumsfeld 2002

7.1 INTRODUCTION

Contrary to the expectations of my study leader and co-leader, this research thesis did happen, but I found the things I didn't know that I didn't know about, to be the most difficult part. For me, this thesis represented a learning process from beginning to end.

The research question was the most difficult part; we spent a full year on an alternative research topic, and only started investigating the RT_{Clin} test in 2013. The process gave me a lot of respect for my fellow researchers who embarked on this journey full time while working full time in practice too.

7.2 LEARNING POINTS

I am pleased with the amount of time I spent formulating the research question. My biggest regret after the pilot study is that I did not incorporate the CONSORT guidelines (Kehoe *et al.* 2009). But this was one thing I didn't know I didn't know. In hindsight, a flow diagram to account for and track each athlete's progress through the trial would have alerted me to the high dropout rate. This would have enabled me to phone and motivate athletes to attend follow-up appointments.

I believe the geography of the fields leads to less medical scrutiny, a high rate of underreporting by athletes and athletes bypassing the medical system. This is a finding that may help change the way rugby players are managed on the field, and it may serve as a reminder of the benefits of more vigilant first aiders.

7.3 CLINICAL PEARLS ACQUIRED

- Formulating and planning the research question is crucial, and presenting it to a research committee was hugely helpful in the focus and formulation of this study.
- CONSORT guidelines: flow diagram, checklist and elaboration document are keys to monitoring the progress of a study.
- Try to find out what you don't know you don't know, quickly!

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APPENDIX A
EVALUATION 1 (E-1)

APPENDIX A

EVALUATION 1 (E-1)

Inclusion Criteria:

A. Registered US rugby player?: Y / N

If Yes then continue.

B. Concussed/ Clinical Suspicion?: Y / N

If Yes then continue.

Exclusion Criteria:

A. Upper limb injury- dominant side? : Y / N

If No then continue.

B. Concussed in the last 6 months?: Y / N

If No then continue.

C. Neurological Disorders?: Y / N

(ADHD/Seizures/Migraine/Brain surgery/Learning Disabilities)

D. Medication?: Y / N

(Anti-epileptic, sedative and opioids)

If No then meets criteria for inclusion to study.

Evaluation 1 (E1)

Study No: ☐☐☐ 1 - 3

1) Date of examination (DD/MM/YY) ☐☐☐☐☐☐ 4 - 9

2) Date of Injury (DD/MM/YY) ☐☐☐☐☐☐ 10 - 15

3) Age ☐☐ 16 - 17

4) 24 – 72h after injury:

I. SCAT3

1) Glasgow Coma Scale (of 15) ☐☐ 18 – 19

2) Symptom Severity Score (of 132) ☐☐ 20 - 21

3) Standardized Assessment of Concussion

i. Orientation (of 5) ☐ 22

ii. Immediate Memory (of 15) ☐ 23

iii. Concentration (of 5) ☐ 24

4) Modified Balance Error Scoring System

i. Double Leg Stance
(of 10)

25 - 26

ii. Single Leg Stance
(of 10)

27 - 28

iii. Tandem Stance
(of 10)

29 - 30

5) Coordination examination
(of 1)

31

6) SAC Delayed Recall
(of 5)

32

II. RT_{clin} measurement (mm)

1) First measurement

33 - 35

2) Second

36 - 38

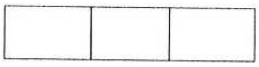
3) Third

39- 41

4) Fourth

42 - 44

5) Fifth



45 – 47

6) Sixth

48 - 50

7) Seventh

51 - 53

8) Eighth

54 - 57

9) Ninth

58 - 60

10) Tenth

61 – 63

III. CogState Sport:

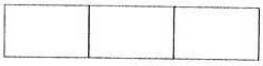
1) Simple Reaction Time: (ms)

64 – 66

5) Complex Reaction Time (ms)

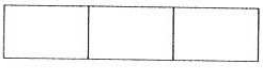
67 – 69

6) Working Memory Test



70 – 72

4) Learning Memory Task



73 - 75

APPENDIX B
EVALUATION X (E-X)

APPENDIX B

EVALUATION X (E-X)

Study No: ☐☐☐ 76 - 78

1) Date of examination (DD/MM/YY) ☐☐☐☐☐☐ 79 - 84

2) Date of Injury (DD/MM/YY) ☐☐☐☐☐☐ 1 - 6

3) Age ☐☐ 7 - 8

4) 24 – 72h after injury:

I. SCAT3

1) Glasgow Coma Scale (of 15) ☐☐ 9 – 10

2) Symptom Severity Score (of 132) ☐☐ 11 - 12

3) Standardized Assessment of Concussion

iv. Orientation (of 5) ☐ 13

v. Immediate Memory (of 15) ☐ 14

vi. Concentration (of 5) ☐ 15

4) Modified Balance Error Scoring System

I. Double Leg Stance

(of 10)

16 - 17

II. Single Leg Stance

(of 10)

18 - 19

III. Tandem Stance

(of 10)

20 - 21

5) Coordination examination

(of 1)

22

6) SAC Delayed Recall

(of 5)

23

II. RT_{clin} measurement (mm)

1. First measurement

24 - 26

2. Second

27 - 29

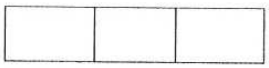
3. Third

30- 32

4.Fourth

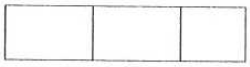
33 - 35

5. Fifth



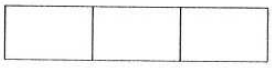
36 – 38

6. Sixth



39 - 41

7.Seventh



42 - 45

8.Eighth

46 - 48

9.Ninth

49 - 51

10.Tenth

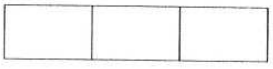
52 – 54

1. CogState Sport:

1)Simple Reaction Time: (ms)

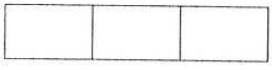
55 – 57

2)Complex Reaction Time (ms)



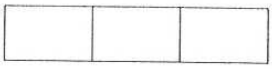
58 – 60

3)Working Memory Test



61 – 63

4)Learning Memory Task



64 - 66

APPENDIX C
EVALUATION ASYMPTOMATIC (E-Asym)

APPENDIX C

EVALUATION ASYMPTOMATIC (E-Asym)

Study No: ☐☐☐ 67 - 69

1.Date of examination (DD/MM/YY) ☐☐☐☐☐☐ 70 - 75

2.Date of Injury (DD/MM/YY) ☐☐☐☐☐☐ 76 - 81

3.Age ☐☐ 1 - 2

4.Exam:

I.SCAT3

1.Glasgow Coma Scale (of 15) ☐☐ 3 – 4

2.Symptom Severity Score (of 132) ☐☐ 5 - 6

3.Standardized Assessment of Concussion

i.Orientation (of 5) ☐ 7

ii.Immediate Memory (of 15) ☐ 8

iii.Concentration (of 5) ☐ 9

4.Modified Balance Error Scoring System

iv. Double Leg Stance (of 10) ☐☐ 10 - 11

v. Single Leg Stance (of 10) ☐☐ 12 - 13

vi. Tandem Stance (of 10) ☐☐ 14 - 15

5.Coordination examination (of 1) ☐ 16

6.SAC Delayed Recall (of 5) ☐ 17

II.RT_{clin} measurement (mm)

1.First measurement ☐☐☐ 18 - 20

2.Second ☐☐☐ 21 - 23

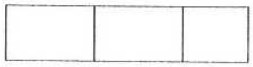
3.Third ☐☐☐ 24 - 27

4.Fourth ☐☐☐ 28 - 30

5.Fifth

31 – 33

6.Sixth



34 - 36

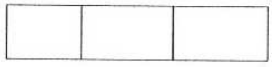
7.Seventh

37 - 39

8.Eighth

40 - 42

9.Ninth



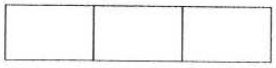
43 - 45

10.Tenth

46 – 48

III.CogState Sport:

1.Simple Reaction Time: (ms)



49 – 51

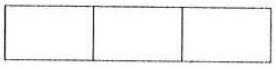
2.Complex Reaction Time (ms)

52 – 54

3.Working Memory Test

55 – 57

4.Learning Memory Task



58 - 60

APPENDIX D
ETHICS APPROVAL UNIVERSITY OF THE FREE STATE

APPENDIX D

ETHICS APPROVAL UNIVERSITY OF THE FREE STATE

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Ms J du Plessis/hv

2014-09-18

REC Reference nr 230408-011
IRB nr 00006240

DR CSvW CARSTENS
DIVISION OF SPORT AND EXERCISE MEDICINE
MULLER POTGIETER BUILDING
FACULTY OF HEALTH SCIENCES
UFS

Dear Dr Carstens

ECUFS 103/2013
PROJECT TITLE: CLINICAL REACTION TIME: AN EFFECTIVE OUTCOME BASED MEASUREMENT TOOL INFLUENCING DECISION MAKING IN THE MANAGEMENT OF SPORTS RELATED CONCUSSION.

1. You are hereby kindly informed that at the meeting on 16 September 2014 the Ethics Committee approved the following:

   - ***Amendment to the protocol***

2. Committee guidance documents: Declaration of Helsinki, ICH, GCP and MRC Guidelines on Bio Medical Research. Clinical Trial Guidelines 2000 Department of Health RSA; Ethics in Health Research: Principles Structure and Processes Department of Health RSA 2004; Guidelines for Good Practice in the Conduct of Clinical Trials with Human Participants in South Africa, Second Edition (2006); the Constitution of the Ethics Committee of the Faculty of Health Sciences and the Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines.

3. Any amendment, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

4. The Committee must be informed of any serious adverse event and/or termination of the study.

5. All relevant documents e.g. signed permission letters from the authorities, institutions, changes to the protocol, questionnaires etc. have to be submitted to the Ethics Committee before the study may be conducted (if applicable).

6. A progress report should be submitted within one year of approval of long term studies and a final report at completion of both short term and long term studies.

7. Kindly refer to the ETOVS/ECUFS reference number in correspondence to the Ethics Committee secretariat.

Yours faithfully

PROF WH KRUGER
CHAIR: ETHICS COMMITTEE

APPENDIX E

PERMISSION DIRECTOR MATIES SPORT

APPENDIX E

PERMISSION DIRECTOR MATIES SPORT

UNIVERSITEIT • STELLENBOSCH • UNIVERSITY
jou kennisvennoot • your knowledge partner

14 October 2013

Dr Charl Carstens
Devonvale Estate
Stellenbosch

Dear Dr Carstens

Concerning research project: ***The Clinical Reaction Time as part of a standardized concussion assessment battery***

The researcher has institutional permission to solicit the participation of Maties Rugby Club rugby players for the purpose of this research project as stipulated in the research proposal.
This permission is subject to the following conditions:

- the researcher obtains permission from the Maties Rugby Club management to proceed with this study,
- the researcher obtains the participants' full informed consent for all facets of their participation in this study,
- participation is voluntary,
- participants may withdraw at any time,
- data that is collected may only be used for the purpose of this study,
- the privacy of individuals must be respected and protected.

Best wishes,

Jan Botha
Senior Director: Institutional Research and Planning

Afdeling Institusionele Navorsing en Beplanning • Institutional Research and Planning Division
Privaatsak/Private Bag X1 • Stellenbosch • 7602 • Suid-Afrika/South Africa
Tel. +27 21 808 3967 • Faks/Fax +27 21 808 4533

APPENDIX F

CONSENT FORM

APPENDIX F

CONSENT FORM

CONSENT TO PARTICIPATE IN RESEARCH

The Clinical Reaction Time Test as part of a standardized concussion assessment battery.

You have been asked to participate in a research study.

You have been informed about the study by Dr Charl Carstens.

You may contact Dr Charl Carstens at 072 7791747 any time if you have questions about the research or if you are injured as a result of the research.

You may contact the Secretariat of the Ethics Committee of the Faculty of Health Sciences, UFS at telephone number (051) 4052812 if you have questions about your rights as a research subject.

Your participation in this research is voluntary, and you will not be penalized or lose benefits if you refuse to participate or decide to terminate participation.

If you agree to participate, you will be given a signed copy of this document as well as the participant information sheet, which is a written summary of the research.

The study will monitor the recovery after a concussion. We will follow the standard concussion protocol at Maties Rugby Club but with a new reaction time test added. Grabbing a falling weighted ruler will test the participant's reaction time. This test will be done on the day of the concussion, two days later, when the participant has recovered and then twice in the following four days. This will mean at least two or three quick tests added in the week after a concussion. It is estimated we will test up to 150 athletes from Maties Rugby Club in the year of the study.

The research study, including the above information has been verbally described to me. I understand what my involvement in the study means and I voluntarily agree to participate.

_____ _____

Signature of Participant Date

INFORMATION DOCUMENT

The Clinical Reaction Time Test as part of a standardized concussion assessment battery.

Dear Participant

We, Dr Charl Carstens (researcher) and Dr Pierre Viviers (study leader), are doing research on a new simple test for sport concussion assessment. Research is just the process to learn the answer to a question. In this study we want to learn how a clinical reaction time test may be used in the days following recovery from a concussion.

We are asking/inviting you to participate in a research study.

The study will monitor the recovery after a concussion. We will follow the standard concussion protocol at Maties Rugby Club but with a new reaction time test added. Grabbing a falling weighted ruler will test the participant's reaction time. This test will be done on the day of the concussion, two days later, when the participant has recovered and then twice in the following four days. This will mean at least two or three quick tests added in the week after a concussion. It is estimated we will test up to 150 athletes from Maties Rugby Club in the year of the study.

There are no risks to you in participating in this study.

The added benefit to you would be even closer monitoring of your recovery after a concussion.

Participation is voluntary**,** and refusal to participate will involve no penalty or loss of benefit. The participant may discontinue the study at any time without penalty.

Efforts will be made to keep personal information confidential. Absolute confidentiality cannot be guaranteed. Personal information may be disclosed if required by law.
The Ethics Committee of the Faculty of Health Sciences, University of Free State and Stellenbosch may inspect and/or copy our research records for quality assurance and data analysis.

If results are published, this may lead to identification of Maties Rugby Club's participation.

Contact details of researchers – for further information/reporting of study-related adverse events: Dr Charl Carstens (072 7791747) or Dr Pierre Viviers (021 808 3492).

Contact details of Secretariat and Chair: Ethics Committee of the Faculty of Health Sciences, University of the Free State – for reporting of complaints/problems: Telephone number (051) 4052812

TOESTEMMING TOT DEELNAME AAN NAVORSING

Kliniese Reaksie Tyd as deel van n gestandardiseerde konkussie evaluerings battery.
U is versoek om aan ‘n navorsingstudie deel te neem.
U is oor die studie ingelig deur Dr Charl Carstens.
U kan Dr Charl Carstens enige tyd kontak by 072 7791747 indien u vrae oor die navorsing het of as gevolg van die navorsing beseer is.
U kan die Sekretariaat van die Etiekkomitee van die Fakulteit Gesondheidsweteskappe, UV by telefoonnommer (051) 4052812 kontak indien u enige vrae het oor u regte as ‘n proefpersoon.

U deelname aan hierdie navorsing is vrywillig, en u sal nie gepenaliseer word of voordele verbeur as u weier om deel te neem of besluit om deelname te staak nie.

As u instem om deel te neem, sal ‘n ondertekende kopie van hierdie dokument sowel as die deelnemerinligtingsblad, wat ‘n geskrewe opsomming van die navorsing is, aan u gegee word.

Hierdie studie sal die herstel na ‘n konkussie monitor. Die normale konkussie protokol van Maties Rugbyklub sal gevolg word plus ‘n kliniese reaksietyd toets. Hierdie toets bestaan uit ‘n liniaal met ‘n gewiggie te laat val en vang om reaksietyd te bereken. Hierdie toets sal bygevoeg word op die dag van ‘n konkussie, twee dae later, weer as die deelnemer kliniese herstel het en dan weer twee keer in die volgende vier dae. Dit beteken ‘n ekstra twee of drie keer hierdie toets te doen nog by die normale protokol. Ons verwag tot 150 atlete te ondersoek van Maties Rugbyklub in die een jaar van die studie.

Die navorsingstudie, insluitend die bogenoemde inligting is verbaal aan my beskryf. Ek begryp wat my betrokkenheid by die studie beteken en ek stem vrywillig in om deel te neem.

_____ _____

Handtekening van deelnemer Datum

INLIGTINGSDOKUMENT

Kliniese Reaksie Tyd as deel van n gestandardiseerde konkussie evaluerings battery.

Geagte Deelnemer

Ons, Dr Charl Carstens (navorser) en Dr Pierre Viviers (studie leier), is besig om navorsing oor ‘n eenvoudige reaksietyd toets na ‘n sport konkussie te doen. Navorsing is slegs die proses waardeur die antwoord op ‘n vraagstuk verkry word. In hierdie studie wil ons leer hoe 'n kliniese reaksietyd toets gebruik kan word in die herstel proses van konkussie.

Ons versoek/nooi u uit om aan ‘n navorsing studie deel te neem.

Hierdie studie sal die herstel na ‘n konkussie monitor. Die normale konkussie protokol van Maties Rugbyklub sal gevolg word plus ‘n kliniese reaksietyd toets. Hierdie toets bestaan uit ‘n liniaal met ‘n gewiggie te laat val en vang om reaksietyd te bereken. Hierdie toets sal bygevoeg word op die dag van ‘n konkussie, twee dae later, weer as die deelnemer kliniese herstel het en dan weer twee keer in die volgende vier dae. Dit beteken ‘n ekstra twee of drie keer hierdie toets te doen nog by die normale protokol. Ons verwag tot 150 atlete te ondersoek van Maties Rugbyklub in die een jaar van die studie.

Daar is geen risiko verbonde aan deelname.
Die voordeel vir die deelnemer is nog meer noukeurige monitering van sy konkussie herstel.

Deelname is vrywillig, en weiering om deel te neem sal geen boete of verlies van voordele waarop die deelnemer andersins geregtig is behels nie; die proefpersoon kan te eniger tyd aan deelname onttrek sonder boete of verlies van voordele waarop die proefpersoon andersins geregtig is.

Daar sal gepoog word om persoonlike inligting vertroulik te hou. Volkome vertroulikheid kan nie gewaarborg word nie. Persoonlike inligting kan bekend gemaak word as die wet dit vereis.
Organisasies wat u navorsingsrekords mag ondersoek en/of kopieer vir kwaliteitsversekering en data-analise sluit groepe soos die Etiekkomitee van die Fakulteit Gesondheidswetenskappe, Universiteit van die Vrystaat en Stellenbosch.

As die resultate gepubliseer word kan dit lei tot identifikasie van die Maties Rugbyklub se betrokkenheid.

Kontakbesonderhede van navorser(s) – Vir verdere inligting/rapportering van studieverwante newe-effekte: Dr Charl Carstens (072 7791747) en Dr Pierre Viviers (021 808 3492).

Kontakbesonderhede van die Sekretariaat en Voorsitter: Etiekkomitee van die Fakulteit Gesondheidswetenskappe, Universiteit van die Vrystaat – vir rapportering van klagtes/probleme: Telefoonnommer (051) 4052812.