

# **Reliability of baseline concussion test results in youth athletes from two consecutive sports seasons**

**A dissertation submitted by Jeanette Coetzer (29375330) in fulfilment of the requirements for the Master Sports Science from the University of Pretoria.**

13 February 2018



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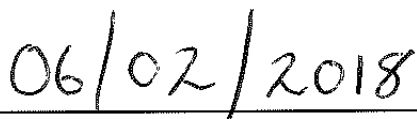
# Declaration

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A handwritten signature in black ink, appearing to be 'J. Coetzer', written over a horizontal line.

(Signature)

A handwritten date '06/02/2018' in black ink, written over a horizontal line.

(Date)

# Acknowledgements

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# List of Abbreviations

- mTBI – Mild traumatic brain injury.
- CTE – Chronic traumatic encephalopathy
- KD – King-Devick test
- LOC – Loss of consciousness
- MRI - Magnetic resonance imaging
- CT - Computed tomography
- RTP – Return to play
- ICC - Interclass correlation coefficient
- SARU – South African rugby union

# Abstract

**Background:** Concussion is a common injury reported in high velocity or contact sport, and a large amount of controversy regarding set protocols for proper management still remains. However, neuropsychological testing, done in accordance with the baseline method, is widely accepted as one of the safest management methods of a concussion. The baseline compared with post-injury testing protocol improves the neuropsychological test's ability to quantify cognitive decline.

However, the period that the baseline remains valid is unknown, and it is suggested that it should be re-assessed periodically to accommodate natural growth and development of the brain, especially in children and adolescents.

**Aim:** To determine the test-retest reliability of baseline values for two consecutive years for both the King-Devick and the Cogstate tests.

**Methods:** A prospective study design, conducted over a two year period, where each athlete acted as his/her own control was used. The test scores and the difference between baseline scores were recorded as the quantitative data for this study.

The study sample consisted out of high school, male and female, students (age 13 to 18) that participated in any school-related sport. Parental consent and participant assent were obtained prior to the sporting season.

This study included the baseline values of the King-Devick test and the computer-based Cogstate sports test.

## **Results:**

**King-Devick test:** There is a statistically significant difference ( $p = 0.004$ ) between 2016 and 2017 baseline values with a low to medium effect size (Cohen's  $D$ : 0.38). Test-retest reliability was found to be low (0.54) between 2016 and 2017 baseline values, and unfit for clinical standards.

**Cogstate sport test:** A statistically significant difference was observed for task one (psychomotor task) ( $p = 0.003$ ) and task two (visual attention task) ( $p = 0.005$ ). No

statistically significant difference was seen for task three (visual learning) ( $p = 0.703$ ) and task four (working memory) ( $p = 0.149$ ). All effect sizes were low to poor (Cohen's  $D$ : - 0.324 to -0.044). Low test-retest reliability (0.58 to 0.17) was found for each task between 2016 and 2017 baseline values.

**Conclusion:** The findings of this study indicate that a new baseline should be conducted pre-season for each sporting season. This is to control for the test-retest reliability scores that decline with time, and for the changes in cognitive performance accompanied with maturation.

**King-Devick test:** The two main factors are sex age of the participant, more prominent under younger ages.

**Cogstate sport test:** Sex does not seem to be a factor, only age, more prominent in the younger ages.

Keywords: Concussion; Baseline; Cogstate; King-Devick; Adolescents; Sport; Age; Sex

# Chapter 1 – Research Question

## 1.1 Introduction

The appropriate management of, and return to play decisions during sport-related concussion are currently one of the most widely debated issues in the sporting community. The complexity of concussion has given rise to a need for the development of new diagnostic and management tools in an attempt to understand the pathophysiology and evolving nature of a concussive injury.<sup>[1]</sup>

Recurrent head injuries are connected to motor cortex dysfunction, early dementia and plaque build-up in the brain also referred to as chronic traumatic encephalopathy (CTE).<sup>[1]</sup> Thus, the swift identification of concussion and appropriate athlete management is essential for the athlete's long-term health and athletic/sporting career.<sup>[1]</sup>

## 1.2 Defining the research problem

Concussion is a common injury reported in high velocity or contact sport.<sup>[2,3]</sup> Approximately 30% of all incidences of concussion reported in individuals, between the ages of five (5) and 19 years of age, are sport related. Making sport, after road accidents, the second largest contributor to the cause of concussion.<sup>[4,5,6]</sup> Approximately 19% of all high school athletes have suffered at least one concussion while participating in sport.<sup>[7]</sup> It is estimated that concussion contributes to 15% of all sport-related injuries in high school athletes.<sup>[6]</sup> The incidence of concussion may be even higher than documented as many athletes either fail to report incidences or downplay their injuries.<sup>[1,4,8,9,10]</sup>

Standardized tests, such as neuropsychological tests and oculomotor function tests, have ensured its role in the management of concussion within the clinical setting.<sup>[11]</sup> The use of baseline values had been suggested to be one of the best methods for unbiased diagnosis and accurate return to play decision making.<sup>[3]</sup>

The present literature favoring the implementation of baseline testing encourages the use of pre-season baseline testing prior to any practice or competition.<sup>[4,9,12,13]</sup> The knowledge of past concussion history, the presence of mood disorders, learning- or attention deficits and lastly migraine history can prove very helpful in the diagnosis and management of a concussion.<sup>[4,14,15]</sup> Should the athlete sustain a concussive injury during his or her sporting season, his or her after-injury values can be compared to their baseline values for comparison.<sup>[3,16,17]</sup>

### **1.3 Relevance and motivation for the study**

Without proper diagnosis, a concussion may go unnoticed, which could lead to catastrophic outcomes like second impact syndrome or severe long-term cognitive impairments.<sup>[4,11,13]</sup> A large number of institutions still lack the basic knowledge on concussion identification which leads to multiple mismanaged incidences of concussed athletes,<sup>[4,13]</sup> especially in high schools where the developing brain is more susceptible to concussions.<sup>[4]</sup>

The most concerning statistic yet are that only 20% of primary care providers and only 44% of emergency department practitioners indicated that they use recommended guidelines for concussion management.<sup>[6]</sup>

Research on concussion had evolved dramatically over the past few decades, still, there are many questions yet to be answered.<sup>[6]</sup> Current legislation with regards to concussion management does not warrant an annual baseline assessment.<sup>[18]</sup> The 2016 International Consensus Conference on Concussion held in Berlin also stated that there is inconclusive support that warrants the absolute need for baseline neurophysiological testing.<sup>[18,19]</sup> However, the consensus still states that it may be useful in the complete management and decision-making process with regards to a concussion.<sup>[18,19]</sup>

In South Africa, documentation such as the South African Rugby Union's (SARU) Boksmart concussion guidelines are formulated in accordance with World Rugby concussion guidelines (Regulation 10). Early February 2017 a letter was addressed to schools referring to both World Rugby (Appendix A) and SARU protocols (Appendix B). Both these documents offer guidelines on return to play (RTP) protocols and



warrant a player be removed from play but it does not touch on pre-injury concussion protocols such as baseline testing. However, the concussion guidelines on RTP suggest that all signs, symptoms and cognitive deficits should return to a 'pre-concussion' level or if signs existed prior to the injury it should return to 'pre-injury' level (p. 6, World Rugby concussion Guidance, 2015). The referral to 'pre-level' or 'pre-injury' status can be obtained through the process of baseline testing.

According to Mozer et al. (2017), the Centres for Disease Control and Prevention (CDC, 2015) are amongst those favoring the implementation of baseline testing. They state that annual baseline testing contributes valuable insight into individual and subtle cognitive changes.<sup>[18]</sup>

Research had shown that there is an improvement seen in cognitive function between the ninth to eleven graders.<sup>[18]</sup> A study done by Whitford et al. (2007) recorded significant structural changes within the brain during the adolescent period, indicating that changes in cognitive function ought to be expected.<sup>[20]</sup> This emphasizes the value of annual baseline testing, especially in adolescents that exhibit natural maturation in cognitive function, to make informed decisions regarding return to play.

The outcome of this research project could impact the approach and management of concussion in high school athletes profoundly. It will investigate the need for proper and reliable baseline values measured at the correct intervals to compensate for the rapidly developing brain and ever-changing cognitive function of the adolescent brain into adulthood.

## **1.4 The research aim and objectives**

The main aim of this study was to investigate and report the difference in concussion baseline values from one sports season to the next. These results were used to determine test-retest reliability indicating the value of a year old baseline test, should a more recent test not be available.

This study included the baseline values of a neuropsychological test and an oculomotor test often used in the assessment of concussion severity and the return to play decision making. The tests consisted of the King-Devick (KD) test and the computer-based Cogstate sports test. Test-retest coefficients investigated included; psychomotor function, visual attention, working memory, visual learning ability and lastly the combined time score for the KD test.

### **Objectives**

1. The first objective was to determine and quantify changes in baseline values for the KD test and Cogstate sport test for all the involved participants measured at the start of the 2016 and 2017 sports season.
2. The second objective was to determine the significance of the difference between the 2016 and 2017 baseline values, including test-retest reliability in both the KD test and Cogstate Sport tests.
3. The third objective was to determine if differences in baseline values with respect to sex and age observed in objective one were statistically significant for the KD test and Cogstate sport test.

## **1.5 Research approach and design**

The study was a prospective study conducted over a two year period, where each athlete acted as his/her own control. The test scores and the difference between baseline scores were recorded as quantitative data for this study.

## 1.6 Flow of the thesis






The literature review explaining the nature of a concussive injury and the methodology used in this study are described in in Chapters two (2) and three (3) respectively.

Chapter four (4) will present the results obtained in tables and figures. Chapter Five (5) will discuss the results in relation to the existing literature and conclude the study with practical implications, relevant limitations, and recommendations.

## 1.7 Research procedure and strategy

The following flow diagram illustrates the procedures that were followed throughout the study, which will be discussed in detail in Chapter Three (3).

Table 1.1 – Flow of the research process.

1. Obtain approval from the MSc Committee, Faculty of Health Science, University of Pretoria. (Appendix C)	
2. Ethical approval obtained from the Ethics Committee, Faculty of Health Science, University of Pretoria. (Appendix D)	
3. Concussion program followed by Waterkloof High School, Pretoria:	
	Distribution of concussion indemnity letter (Appendix E)
	Information session presented by researcher and attended by parents, coaches, and students
	Collection of signed indemnity letter
	Baseline testing - King Devick and Cogstate
	Input of data into Excel 2013 - after each testing session
	Same procedure for 2016 and 2017 - during the months of Jan through to March.
4. Combine 2016 and 2017 data	
5. Statistical analysis	
6. Thesis write up	

# Chapter 2 – Literature Review.

## 2.1 Introduction

The definition of concussion had been evolving over the past 30 years, and will most likely continue to evolve with the consistent effort and input from the scientific society.<sup>[21]</sup> The dangers of concussion are often overlooked, but in truth, it has become a serious health concern within the sporting community.<sup>[6,22]</sup> This chapter will provide an in-depth review the current literature with regards to concussive incidences and the management thereof amongst adolescents participating in sport.

## 2.2 Literature Overview

This section will give an in-depth review of the current literature regarding the definition, indicators, pathophysiology, mechanism, assessment, and management of a concussive injury.

### 2.2.1 Defining concussion

It is known that a concussive injury is complex and highly individualized in nature, resulting in an array of signs and symptoms along with cognitive deficits making it significantly hard to diagnose and manage.<sup>[6,20,22]</sup> The term “concussion” is often used interchangeably with mild traumatic brain injury (mTBI) as both terms refer to the less severe end of traumatic brain injury and imply that acute neurological dysfunction may be present.<sup>[6,19,23]</sup> A concussion is the most common form of traumatic brain injury and therefore warrants proper consideration.<sup>[19]</sup>

Every four years the International Conference on Concussion in Sport is held to review existing evidence on concussion.<sup>[14,19]</sup> Recent definitions of concussion were addressed in the 2008, 2012 and 2016 consensus statements.<sup>[14,19]</sup>

According to the 2012 and 2016 conferences on concussion held in Zurich and Berlin:<sup>[14,19]</sup>

- A concussion is a brain injury caused by either direct or indirect force to the head, typically resulting in the rapid onset of short-lived impairment of brain function.
- Loss of consciousness occurs in less than 15% of concussion cases and whilst it is a feature of concussion, the loss of consciousness is not a requirement for diagnosis.
- Concussion results in a disturbance of brain function, e.g. memory disturbance and balance impairments, rather than damage to structures such as blood vessels, brain tissue or fractured skull.
- Typically standard neuro-imaging such as a magnetic resonance imaging (MRI) or computed tomography (CT) scans, presents as normal.

## **2.2.2 Indicators of a concussion**

There are various combinations of signs and symptoms, cognitive deficits and balance disorders that may accompany a concussion,<sup>[8,9,11,19]</sup> and all are attributable to pathophysiological changes that occur after injury.<sup>[23]</sup> These signs and symptoms are highly individualized and solely depend upon self-reporting by the athlete.<sup>[6,23]</sup> These signs and symptoms may be present immediately after the incident or develop over a period of time,<sup>[2,19]</sup> usually within 48 hours (Table 2.1 and Table 2.2).<sup>[9,21]</sup> Research reports that 80% to 90% of signs and symptoms self-resolve within seven to ten days.<sup>[1,3,4,6]</sup>

Traditionally, loss of consciousness (LOC) was thought to be the hallmark of a concussive injury, but research indicates otherwise.<sup>[19,24]</sup> A loss of consciousness was reported in only 10% or less of all concussive injuries, thus it is not a prerequisite for a positive diagnosis of a concussion.<sup>[6]</sup> Impaired reaction time seems to be a common and sensitive indicator of lingering cognitive impairment, and can be used to help manage the return to play decisions.<sup>[19,23]</sup>

According to statistics the most common signs and symptoms directly following the incident include; dizziness (83.6% of the sample), headache (65.5%), feeling in a fog (61.8%) and lastly visual disturbances (60%).<sup>[24]</sup> Balance deficits and postural sway

are also a common identifier of a concussion.<sup>[1,11]</sup> Balance deficits tend to return to normal after an estimated 72 hours,<sup>[14,15]</sup> therefore it is not advised as a return to play indicator and only as a side-line /remove from play indicator. However, proprioception and fatigue may also have a confounding effect on balance.<sup>[15]</sup>

Post-concussion syndrome is characterized by an individual presenting with persisting signs and symptoms (Table 2.1 and Table 2.2) beyond the normal period of resolution.<sup>[1,4,14]</sup> The post-concussion syndrome occurs in about 10-20% of concussed individuals.<sup>[21]</sup> This also represents a vulnerable period for the athlete’s brain, lowering the biomechanical threshold and making the force needed for a second concussive injury much less.<sup>[19]</sup> Studies found that persisting signs and symptoms of headaches (lasting 60 hours or more), fatigue and the presence of four or more immediate symptoms may result in a form of post-concussion syndrome.<sup>[24]</sup>

The cognitive deficits suffered by a concussed individual may persist even after the resolution signs and symptoms.<sup>[4,6,7]</sup> Neuropsychological testing plays a big role in the assessment of cognitive deficits.<sup>[4]</sup> The severity, the number of signs and symptoms present and a history of concussion can be used to predict a recovery period.<sup>[14,19]</sup> Research suggests that previous concussions, severe and persisting symptoms and loss of consciousness after injury can all be indicators of prolonged recovery.<sup>[4]</sup>

*Table 2.1 - Signs of concussion.*<sup>[4,8,14]</sup>

Loss of consciousness	Vomiting	Balance problem
Amnesia	Stunned	Seizures or convulsions
Slow speech	Coordination deficits	Dilated or uneven pupils

*Table 2.2 - Symptoms of a concussion.*<sup>[4,8,14]</sup>

Nausea	Dizziness	Sensitive to light
Headache	Visual disturbances	Drowsiness
“Pressure in head”	Fatigue	Irritability
Sadness	Sensitive to noise	Numbness/ tingling
Difficulty concentrating	Dazed	Confusion
Nervous or anxious	Sleep disturbances	Mood disturbances

### **2.2.3 The pathophysiology of concussion**

Underlying the presentation of a concussion is a cellular process called the “Metabolic Syndrome” (MS) characterized by a change in intracellular and extracellular environments.<sup>[4,6,19,21,23,25]</sup> These changes result in a complex cascade of ionic, metabolic and pathophysiological events that are triggered by the injury of neurological/brain tissue.<sup>[4,6,8,19,21,25]</sup> Shortly after the concussive injury, there is a spike in energy demand above the normal requirements to repair the damaged tissue.<sup>[4,21]</sup> In conflict with this energy demand is the decreased blood flow, due to neurovascular constriction and mitochondrial dysfunction, observed in concussed individuals.<sup>[4,6,19,21,23]</sup> This mismatch of energy need and blood supply leaves the brain susceptible and vulnerable.<sup>[4,6,9,21]</sup> The duration of this state can occur within minutes following the incident or take up to several hours to develop, but is usually presents within the first 24 hours and can last for several days.<sup>[19]</sup> During this vulnerable state, a second knock to the head might prove fatal.<sup>[4,6,21]</sup> A second concussion before complete injury resolution will worsen the MS and lead to more severe cognitive deficits.<sup>[4,6,7,9,21]</sup>

### **2.2.4 The mechanism of a concussive injury**

A concussive injury is caused by generated forces that affect the neurological tissue of the brain. These biomechanical forces are either generated by a direct or indirect hit to the head. These forces can be either linear or rotational caused by an acceleration or deceleration of the body/head.<sup>[6]</sup>

Linear applied forces are speculated to produce more focal injuries, whereas rotational applied forces are said to produce both focal and diffuse injuries.<sup>[6]</sup>

A whiplash effect caused by the sudden deceleration of a moving body, like a tackle, or the sudden acceleration of an unmoving body can also generate enough referring force to cause some disruption of the brain’s neurological tissue due to the brain’s inertia.<sup>[6]</sup> This is also termed the ‘linear acceleration-deceleration’ mechanism of concussion and is considered the most common cause of cranial deformation and fractures leading to concussive injuries.<sup>[6]</sup>

The 'rotational acceleration-deceleration' mechanism is much harder to measure but is speculated to contribute the most to soft tissue damage because of the shearing forces that are generated. These rotational forces largely contribute to diffuse axonal injuries that more often lead to subdural hematomas.<sup>[6]</sup>

### **2.2.5 Sub-concussive state**

The phenomenon of a sub-concussive injury is a suspected mild pre-concussive state.<sup>[6]</sup> A sub-concussive state very often shows no visible signs or symptoms that any concussive injury is present, making it a vulnerable and dangerous state.<sup>[6]</sup> It may make an athlete more susceptible to an actual concussive injury should a second hit to the head occur.<sup>[6]</sup> It had been noted that a neuro-inflammatory response may be present and the detrimental effects of this may be accumulative, leading to various states of permanent and long-term damage to the unsuspecting athlete.<sup>[6]</sup> It has even been theorized to lead to the onset of neurodegenerative disorders such as chronic traumatic encephalopathy (CTE).<sup>[6]</sup>

### **2.2.6 Confounding factors in the identification of concussion**

Individuals suffering from pre-injury learning deficiencies, attention and/or mood disorders and migraines pose a challenge to diagnose and to manage.<sup>[4]</sup> These variables appear to cloud post-injury signs, symptoms and cognitive function since they have overlapping signs and/or symptoms.<sup>[4]</sup> In these cases, it is especially valuable to have specific pre-injury documented mood states, signs and symptoms.<sup>[4,12]</sup> The use of medication must also be recorded and managed by a clinician as it may also cloud signs and symptoms.<sup>[4]</sup>

### **2.2.7 Age and sex**

Research has suggested that there may be a difference in the susceptibility and duration of recovery when it comes to sex and age.<sup>[15]</sup> Female athletes and adolescents were noted to be more prone to a protracted recovery course.<sup>[26]</sup> This highlights the need for medical practitioners to recognize these variables and adjust



the management plan accordingly since adolescent female athletes may take longer than the average 7 to 10 days to recover.<sup>[26]</sup>

The immature brain has a more pronounced pathophysiological response, which leads to the conclusion that the youth are even more susceptible to second impact syndrome.<sup>[4]</sup> This is of great concern as statistics indicate that high school athletes sustain concussions easier than college athletes participating in the same sport.<sup>[4]</sup> It seems that the biomechanical threshold for concussion in children and adolescents is lower than in a matured brain. This may be due to the increased plasticity during brain development.<sup>[4]</sup> Some of the main theories on why the developing brain is more susceptible to concussion are the incomplete myelination of brain tissue and ossification of the cranium which results in less protection of the developing cortex.<sup>[12,13]</sup>

Males and females have also been found to perform differently on neuropsychological tests, especially in perceptual-motor speed and visuospatial tasks.<sup>[15]</sup> Another difference is the amount of pre-existing signs and symptoms reported during baseline testing, where males reported 68% and females 78% of the usual signs and symptoms.<sup>[26]</sup> This is important to note and implies the need for individual baseline testing since females and males cannot be accurately assessed on the same norms.<sup>[26]</sup> However, literature available on youth athletes, especially research on sex and age groups, are sparse,<sup>[19]</sup> and no research, done in the South African school setup, could be found.

## **2.2.8 Management of Concussion**

The proper and holistic management of a concussive injury has yet to be established. However, many attempts had been made in an effort to better understand and to propose a management plan. The general consensus is to conduct baseline testing, as part of the preparatory phase, and then to use the player's baseline to help manage their injury after the athlete sustained a concussive injury.<sup>[23,27]</sup>

The initial diagnosis is best left to a medical practitioner with the proper knowledge regarding a concussion. However, once the acute phase had passed it is advised to

seek further management to help guide the athlete through the return to play process. The return to play process involves the monitoring of signs and symptoms as well as slowly reintroducing the athlete to physical activity in a progressive manner.<sup>[23,27]</sup>

## **2.2.9 Tests to assess concussion**

Standardized tests, such as neuropsychological tests and visual-verbal test, have ensured its role in the management of concussion within the clinical setting.<sup>[11]</sup>

### **2.2.9.1 Neuropsychological testing**

Neuropsychological testing is very popular around the world and is described as the cornerstone of concussion management. Neuropsychological tests can include pencil and paper tests or computerized tests, both are considered to be the gold standard in the management of concussion. In the current study only the computerized test, Cogstate Sport, will be discussed.<sup>[3,5,6,12,23]</sup>

Computerized testing has been noted to have both advantages and disadvantages.<sup>[6,22,23]</sup> Advantages include: Testing of large groups simultaneously, less time consuming, electronic recording of results, no human error, and fast processed feedback.<sup>[6,22,23]</sup> Some disadvantages include: less interpersonal instruction, adherence to and comprehension of the test is less closely monitored and lastly it creates more opportunity for distractors.<sup>[6,18,22]</sup>

#### **2.2.9.1.1 Cogstate Sport - neuropsychological test (computerized)**

The Cogstate program is a brief neuropsychological test battery specifically designed to measure cognitive function over repetitive short intervals and to track any cognitive changes during these time intervals. The test is appropriate for short (hours-days) and/or long (weeks-months) time intervals. The test battery consists of four tasks, which takes approximately eight (8) to 15 min to complete.<sup>[3,6]</sup> These tasks include simple stimuli requiring decisive responses within the set rules of each task.<sup>[5]</sup> Due to the fact that the test is computerized, the administration and scoring are automated and thus standardized (Appendix F).<sup>[4,16]</sup>

All four tasks are instructed to be performed accurately and swiftly. All results are measured in milliseconds (ms) to indicate response speed and by a number of errors to assess accuracy.<sup>[5,28,29]</sup>

Research showed that mild traumatic brain injuries presented with impairments in one or more of the above cognitive domains. Concussion falls under the category of a mTBI. Studies show that individuals suffering from a mild traumatic brain injury presented with a relatively larger impairment in the learning task. This cognitive impairment has been speculated to be due to shearing forces admitted onto the neurological tissue by the applied biomechanical forces that caused the injury.<sup>[28]</sup>

The Cogstate brief battery is deemed as a valid test battery.<sup>[28,29]</sup> Each of the four tasks has been found to measure the cognitive domain it was intended to measure. The brief battery has also proven to be sensitive to cognitive impairment in the sense that it successfully detects and tracks cognitive changes.<sup>[28,29]</sup> The test can be administered repeatedly without significant practice effects due to the randomization of stimuli.<sup>[28]</sup> However, the brevity of the battery may limit specificity in the classification of the cognitive injury. But the significant decline in the learning task seen in individuals with mTBI can help to aid in the specificity of the battery towards classifying the injury as a concussion.<sup>[28]</sup> It is suggested that the Cogstate brief battery should not be used in isolation but in conjunction with a more elaborate testing battery.<sup>[28,29]</sup>

#### **2.2.8.2 Visual-verbal test**

The effects of concussion include various aspects of impaired vision, impaired oculomotor speed (65-90% of concussed individuals) and difficulty with saccades (rapid movement of the eye between fixation points).<sup>[29,30,31,32,33,34]</sup> Thus vision based testing might enhance side-line assessment of concussion.<sup>[19,31]</sup> Approximately 50% of the circuits in the brain are involved in vision thus rendering vision extremely susceptible to the effects of a concussion.<sup>[6,30,31,34]</sup>

Examination of the integrity of the visual system can greatly contribute to the successful diagnosis and management of concussion.<sup>[6,31]</sup> Studies show that patients

with concussion had longer saccadic reaction times compared to non-concussed individuals.<sup>[31]</sup>

#### **2.2.8.2.1 The King-Devick test (KD) - visual-verbal test**

The KD test is a visual performance measure and proven to be effective in diagnosing signs and symptoms associated with concussion in the acute phase.<sup>[30,31,33]</sup> The KD test is capable of assessing specific neurological function, which in turn is more evidence-based than subjective symptom checklists.<sup>[31]</sup> The KD test is able to evaluate saccadic eye movement, attention, coordination, and language; all areas known to be affected by a concussive injury.<sup>[6,19,31,33]</sup>

The test largely relies on baseline values, as normative data for adolescents are still not established nor available in general.<sup>[32,33]</sup> The KD test is endorsed by many researchers and deemed a sensitive and reliable test in assessing concussion.<sup>[2,11,30,31,32,33]</sup> High reliability scores have been found in various studies with interclass correlation coefficient (ICC) values ranging from 0.95 (95% CI: 0.87, 1.0) to 0.97 (95% CI: 0.90, 1.0) in studies of boxers and MMA fighters and 0.95 (95% CI: 0.85, 1.1) among collegiate athletes.<sup>[21]</sup>

Specific time frames for administering the KD test post-concussion has not yet been clearly defined but studies show that it is most effective within the first 72 hours post-injury, thus placing it in the side-line category of concussion management tools making it a good indicator to predict the end of the acute phase.<sup>[6,11,19]</sup> Research suggests that the KD test should not be administered within the first 15 minutes following a concussive injury.<sup>[6,31]</sup> The reason being that directly following the injury there is a complex ionic cascade taking place within the brain, during which cognitive dysfunction is manifested.<sup>[31]</sup> Administering the KD test within the first 15 min post-injury may present false negatives.<sup>[6,31]</sup> Fatigue may be a confounding factor, thus a rest period of 15 minutes is advised.<sup>[6,32]</sup>

Signs of a learning effect between the first and second test trial in certain studies have been noted, this just supports the need for an annual baseline as it might have an effect on consecutive baseline scores.<sup>[2,31]</sup> In order to help counter this learning effect,

two sets of test cards have been developed to be used interchangeably.<sup>[31]</sup> Another important characteristic of the KD test is that it is seemingly unaffected by distractions within the environment, including noise and movement.<sup>[30]</sup> The test scores have also been noted to improve with age, due to the improvement of the developing brain and it is suggested to be administered regularly.<sup>[17]</sup>

The administering of the KD test is relatively simple and inexpensive.<sup>[30,33,35]</sup> The test itself takes between one (1) to two (2) minutes to conduct making it more time effective than other side-line tools.<sup>[19,30,31,32,34,36]</sup> The KD test can provide coaches with instant feedback thus aiding in the remove from play decision.<sup>[19,31,33]</sup> Currently, research reports that a three-second deviation from baseline is still acceptable but that five seconds or more is an indication of a concussion, studies confirmed a significant drop in after injury times compared to baseline times.<sup>[2,18,19,31]</sup>

The KD test is based on a verbal-visual format to provide quantified feedback simulated in a reading environment.<sup>[35]</sup> The KD test uses rapid number naming to assess the speed and accuracy of saccadic eye movement, attention, oculomotor speed and language.<sup>[2,19,30,31,32,34,35,37]</sup>

### **2.2.10 Return to play following a concussive injury.**

Although a concussion is seen as a less severe brain injury, the mismanagement of a concussed individual can be fatal, especially when the individual returns to play before complete injury resolution. Research suggests a lowered neural activation within a concussed brain, thus physical activity before complete injury resolution may result in a prolonged recovery period.<sup>[4,12]</sup>

A new return to play (RTP) protocol was first suggested in the 2012 International Consensus Conference on Concussion held in Zurich.<sup>[14]</sup> It has been developed to systematically and slowly progress the athlete through a series of physical sessions to ensure a safe recovery period.<sup>[6,14,23]</sup> This protocol has been based on the biomechanical concepts of a concussion.<sup>[6,23]</sup> Originally the 'three strike rule' was used in its basic form, three concussions and you're suggested to stop sports participation

permanently. RTP protocols have since become much more individualized and sport-specific following a progressive step pattern (Appendix G).<sup>[6]</sup>

The main goal of the implementation of a RTP protocol is to prevent a secondary injury or pre-mature return to play.<sup>[6]</sup> The golden rule is to ensure that the concussed athlete's cognitive values have returned to baseline levels and that he or she is completely asymptomatic before starting the RTP process and that no underlying signs and symptoms resurface during the RTP protocol.<sup>[6]</sup> Thus, it is important to note which signs and symptoms were recorded at baseline testing and then to use sound judgment regarding the management around those pre-existing signs and symptoms.<sup>[23]</sup>

When working with athletes under the age of 18, a more adaptable and conservative protocol must be implemented than compared to adults.<sup>[6,23]</sup> A minimum of 24 hours rest must be given in between sessions or if a sign or symptom is suspected.<sup>[6]</sup>

However, following the 2016 International Consensus Conference on Concussion held in Berlin, it was concluded that there is still insufficient evidence to completely rule out the potential benefit of gradual exercise after the first acute phase (48 hours, post injury).<sup>[19]</sup> New research is currently investigating the effect of gradual and progressive physical activity that does not exceed the symptom-exacerbation threshold.<sup>[19]</sup>

Although the evidence is compelling, much research is still needed to provide definite guidelines for diagnosis and management of concussion injuries-especially in youth athletes. The decision on RTP must weigh the potential long-term effects against the short-term demands of the situation. The safest call is removal from play following the injury and then the application of a multimodal approach towards the concussed athlete.<sup>[8,12,14]</sup>

### **2.2.11 The ugly side of concussion**

Besides the general pathophysiology of a concussion, along with the general signs and symptoms, balance and cognitive deficits that accompany it, there is an ominous side to a concussive injury or history of concussive injuries. After a concussive injury

occurs the brain is left in a vulnerable state for an undetermined period of time following the incident.<sup>[6]</sup> This makes the athlete much more susceptible to a second injury should the athlete receive another knock to the head before complete injury resolution.<sup>[6]</sup>

A second impact to the head before complete injury resolution will worsen the metabolic syndrome and lead to more severe cognitive deficits.<sup>[4,6,7,9,13,21]</sup> A loss of auto-regulation of the brain's blood flow may occur leading to; intracranial pressure, cerebral edema and ultimately death. This phenomenon is known as Second Impact Syndrome.<sup>[4,6,7,8,13,21]</sup> The occurrence of "Second Impact Syndrome" is more prominent in children and adolescents under the age of 18.<sup>[4,6,8,13,21,25,27]</sup>

Several research articles suggest the accumulative effect of a concussive injury, studies suggest chronic structural abnormalities in the brain after multiple concussions.<sup>[1,19]</sup> It is suggested that repetitive incidents may lead to permanent long-term damage to the neurological tissue in the brain or neurodegenerative disorders such as chronic traumatic encephalopathy (CTE).<sup>[1,6,19,23,30,38]</sup> CTE has been found in athletes as young as 18 who have died with a history of concussion.<sup>[6]</sup> Patients suspected of suffering from CTE exhibit similar characteristic to those diagnosed with Parkinson's disease, which includes changes in memory, behaviour, speech, personality, and gait.<sup>[6]</sup>

The exact pathophysiology pathways are still unclear but speculations and studies indicate that repetitive concussive injuries or sub-concussive injuries may be responsible for various negative consequences later in life such as depression and anxiety.<sup>[15,26]</sup> It is reported that athletes that suffered a concussion show higher incidences of cognitive impairment and depression than athletes with no previous concussion.<sup>[8]</sup> Athletes with a history of concussion also showed decreased results in neuropsychological testing.<sup>[8]</sup>

The very reason that research on concussion is so important is not just because second impact syndrome can be fatal, but because a history of concussions or the mismanagement of a concussion can lead to long-term, or even permanent, cognitive impairments.<sup>[13,21,25]</sup> It's no surprise that the term 'silent epidemic' has been used to describe concussion.<sup>[30]</sup> The lack of visual evidence and direct diagnosis makes it elusive and very difficult to manage the injury.<sup>[30]</sup>

Research supports the negative effect concussion has on cognitive function. A concussion may lead to poor concentration, difficulty in verbal and visual memory and recalling, these deficits all contribute to poor academic performance.<sup>[6]</sup> Evidence support that concussed individuals have lower academic grades during the concussed period.<sup>[6]</sup> Cognitive rest is recommended for a certain period following the concussion to help prevent exacerbation of any signs and symptoms.<sup>[6]</sup> This will require either a leave of absence from school or adaptation to the workload.<sup>[6]</sup>

At the other end of the scale there comes a point where the benefits of rest are outweighed by the negative effects of being held back from participation.<sup>[26]</sup> Some athletes may find it emotionally stressful when they are kept from activity or school work for too long in fear that they will fall behind.<sup>[26]</sup> To avoid these negative feelings the RTP protocol must be adjusted accordingly.<sup>[26]</sup>



# Chapter 3 – Methodology

## 3.1 Introduction

The methodology outline of this research study is discussed in Chapter three. The process of sample selection, data collection, data analysis, and data interpretation is stipulated in accordance with the determined aims and objectives.

## 3.2 Research approach and design

The study was a prospective study conducted over a two year period, where each athlete acted as his/her own control. The test scores and the difference between baseline scores were recorded as the quantitative data for this study.

The main aim of this study was to investigate and report the difference in concussion baseline values from one sports season to the next. These results were used to determine test-retest reliability indicating the value of a year old baseline test, should a more recent test not be available.

This study included the baseline values of a neuropsychological test and an oculomotor test often used in the assessment of concussion severity and the return to play decision making. The tests consisted of the King-Devick test and the computer-based Cogstate sports test. Test-retest coefficients investigated included; psychomotor function, visual attention, working memory, visual learning ability and lastly the combined time score for the KD test.

### **The objectives of the study were:**

1. The first objective was to determine and quantify changes in baseline values for the KD test and Cogstate sport test for all the involved participants measured at the start of the 2016 and 2017 sports season.
2. The second objective was to determine the significance of the difference between the 2016 and 2017 baseline values, including test-retest reliability in both the KD test and Cogstate Sport tests.

3. The third objective was to determine if differences in baseline values with respect to sex and age observed in objective one were statistically significant for the KD test and Cogstate sport test.

### **3.3 Research procedures and strategy**

This section will outline the steps and guidelines followed to implement this study. The ethical considerations, setting, participant selection, concussion test procedures and statistical analysis will be discussed in detail.

#### **3.3.1 Ethical considerations**

Prior to the commencement of the data-collecting process, the research protocol was submitted to and approved by the MSc committee of the faculty of Health Sciences and ethical clearance was obtained from the Ethics Committee of the Faculty of Health Sciences, University of Pretoria (No155/2016) shown in Appendix D. The following considerations were made to ensure that the study was conducted in an ethical manner.<sup>[39]</sup>

##### **3.3.1.1 Informed consent**

A letter was sent to all the parents whose children were involved in the sport. This letter gives a brief overview of what concussion is and the benefits of being involved in a concussion program. Attached to this letter was an indemnity form the parents had to sign either indicating “yes” or “no” for participating in the school's program (Appendix E).

Every single student that completed their baseline tests must have submitted one of these signed letters. This letter clearly stated that the data would be used for research and that the identity of the participant would be kept anonymous.

##### **3.3.1.2 Non-invasive**

All the test performed were non-invasive. The King-Devick test is a rapid number naming test where the individual was required to only read out the numbers on the test

cards. The Cogstate is a computerized test, the individual was subjected to four tasks that had to be completed using only the keyboard.

### **3.3.1.3 The right to privacy**

As the individual has the right to privacy, results were filed and locked in a filing cabinet. In a case where an individual was diagnosed with a mood disorder or attention/learning disorder that knowledge was safely filed and not shared.

### **3.3.1.4 The right to remain anonymous**

The indemnity form stated that only the data would be used, no individual's name would be associated with the specific data. The data would only be used in terms of male/female and according to age. Thus the individual would be referred to as e.g. male aged 15, no identities would be revealed within the study.

### **3.3.1.5 The right to confidentiality**

The individual had the right to expect that their files would be kept confidential. As mentioned the files were locked inside a filing cabinet and any computer holding information on the study/program data was password protected. The data of and specifics of an individual were not discussed or compared with other participants. The data was only discussed with the medical doctor involved in the program as well as the sports coach, as stated in the indemnity form.

### **3.3.1.6 The right to expect researcher responsibility**

The participant also had the right to expect that the researcher involved in this study would abide by all ethical responsibilities. All attempts to make the participant feel safe and assured that all personal/ private or confidential information would be kept safe and anonymous were made. The experimenter also took the responsibility to treat each participant with respect and human dignity seriously in all the phases of the study (Appendix H & I).

### **3.3.2 Setting**

The project was administered from Hoërskool Waterkloof, a high school in Pretoria, during the schools' pre-season. The baseline tests were conducted throughout February and March in both 2016 and 2017.

Classrooms were used in the process of collecting baseline data. The Information Technology (IT) classrooms could accommodate up to 25 individuals at a time during the Cogstate test. Different classrooms were used to complete the King-Devick test. Both tests were conducted outside of school hours, thus noise and distractions were limited. A letter of permission was obtained from Hoërskool Waterkloof to make use of their facilities and to conduct the study (Appendix J).

### **3.3.3 Participant selection criteria**

All the high school students, from grade 8 to 12 that participated in any school-related sport are urged to take part in the school's concussion program. However, participation is not compulsory, and thus not every student enrolls. The school asks a registration fee of R100 to pay for the Cogstate Sport ID's and to cover additional administrative and stationary cost. The decision to enrol in the program is solely the parent's.

To promote program adherence each year group was informed during assembly, and guided on how to enrol at the beginning of the year. The program initiative was also announced, multiple-times, via all the communication channels.

The parents/legal guardians of all the learners that were enrolled in the concussion management program gave consent by signing an indemnity form that indicated their data will be subject to research (Appendix E). However, those enrolled in the program also had the option to refuse the use of their data for this study.

The poor adherence to the program ought to warrant a study of its own to identify possible justifications, regardless the selection bias seen here was not intentional. It's merely a reflection of the reality in high school settings when it comes to concussion program adherence.

### **3.3.3.1 Inclusion criteria**

All the learners from Hoërskool Waterkloof, regardless of the type of sport they participated in, were considered for this study. Only learners that have signed and submitted an indemnity letter were accepted for this study. Only learners that completed a baseline test in 2016 and 2017, for the same test were included.

### **3.3.3.2 Exclusion criteria**

All athletes born in 2003, new grade 8 students, were excluded as they would not have completed the test in 2016. All the students that failed to complete the baseline test in either 2016 or 2017 were also excluded from the study. Any participant that had an incomplete or incorrectly completed baseline test were excluded.

## **3.3.4 Measuring tools**

In this study, the Cogstate and the KD test were included in the baseline testing levels.

### **3.3.4.1 Cogstate**

The following equipment and procedures were used when the Cogstate test was administered.<sup>[3,5,28,29]</sup>

#### **Equipment used:**

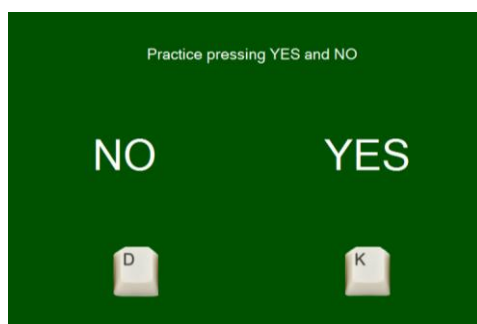
- Desktop computer with the Cogstate program
- Printer and paper for the printout
- A quiet classroom with limited distractors

#### **Administration of test:**

Each individual entering the IT classroom needed to sign in and was seated in front of a computer. All instructions were given, and the test was explained in full.

Each task is presented as a card game, with a universal deck of playing cards as the stimulus set.<sup>[5]</sup> Each task needs either a “yes” or a “no” answer, the “K” key on the keyboard represents “yes” while the “D” key represents “no” as illustrated by the screenshot in Figure 2.1.<sup>[28]</sup>

Figure 2.1 – A screenshot of the response instructions in the Cogstate computerized test.



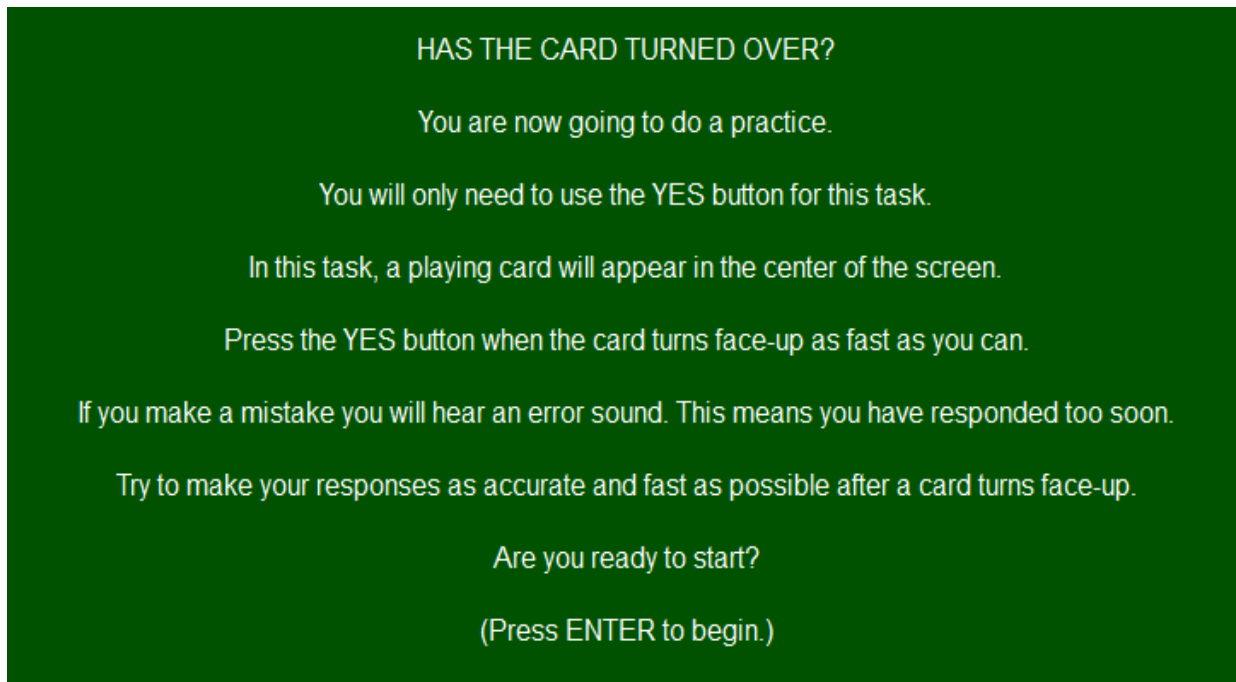
**The four tasks include:**

**Task one - A detection task (psychomotor function).**<sup>[3,5,28,29]</sup>

- The simple reaction time task is used to measure vigilance and attention.
- The individual is faced with a single and simple question “has the card turned over?” the “yes” key must be pressed as fast as possible each time the card turns over.
- The task ends after 35 trials and all anticipatory responses are excluded.

In Figure 2.2 is the screenshot of how the instructions for task one were presented to participants on the computer screen during Cogstate sport baseline testing.

Figure 2.2 – A screenshot of the instructions for task one in the Cogstate test.



**Task two - An identification task (visual attention).**<sup>[3,5,28,29]</sup>

- The choice reaction time task consists out of motor, perceptual and attention processes.
- The task represents processing speed.
- The individual is faced with a single and simple question “is the card red?” the “yes” or “no” key must be pressed as fast as possible each time the card appears.
- The task ends after 30 trials and all anticipatory responses are excluded.

In Figure 2.3 is the screenshot of how the instructions for task two were presented to participants on the computer screen during Cogstate sport baseline testing.

*Figure 2.3 – A screenshot of the instructions for task two in the Cogstate test.*

## IS THE CARD RED?

You are now going to do a practice.

You will need to use both the YES and NO buttons for this task.

In this task, a playing card will appear in the center of the screen.

As soon as it turns face-up you must decide: is the color of the card red?

If it is red, press the YES button.  
If it is not red, press the NO button.

If you make a mistake you will hear an error sound.

Try to make your responses as accurate and fast as possible after a card turns face-up.

Are you ready to start?

(Press ENTER to begin.)

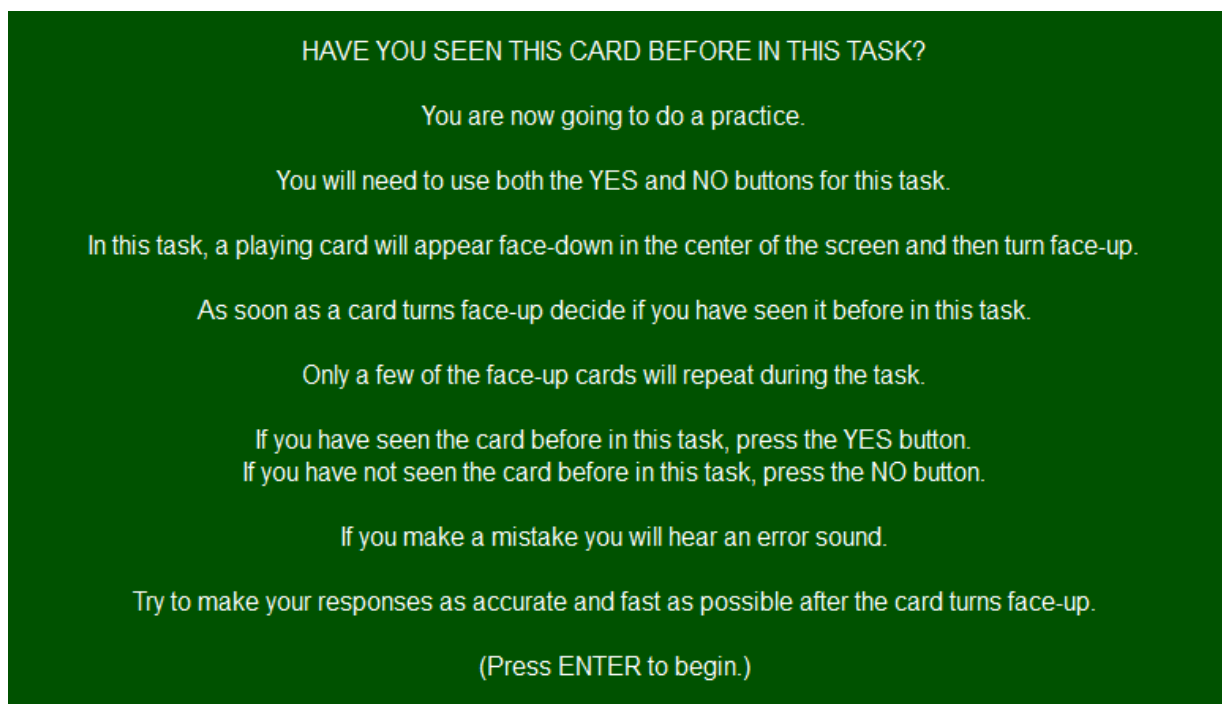


### **Task three - A one card learning task (visual learning).**<sup>[3,5,28,29]</sup>

- The continuous recognition task requires the person to learn a series of stimuli via repeated exposure.
- The person is forced to distinguish learned information from novel information.
- The individual is faced with a single and simple question “have you seen this card before in this task?”, the “yes” or “no” key must be pressed as fast as possible each time the card appears. Six cards are drawn at random and repeated throughout the task combined with distractor cards.
- The task ends after 80 trials and all anticipatory responses are excluded.

In Figure 2.4 is the screenshot of how the instructions for task three were presented to participants on the computer screen during Cogstate sport baseline testing.

*Figure 2.4 – A screenshot of the instructions for task three in the Cogstate test.*

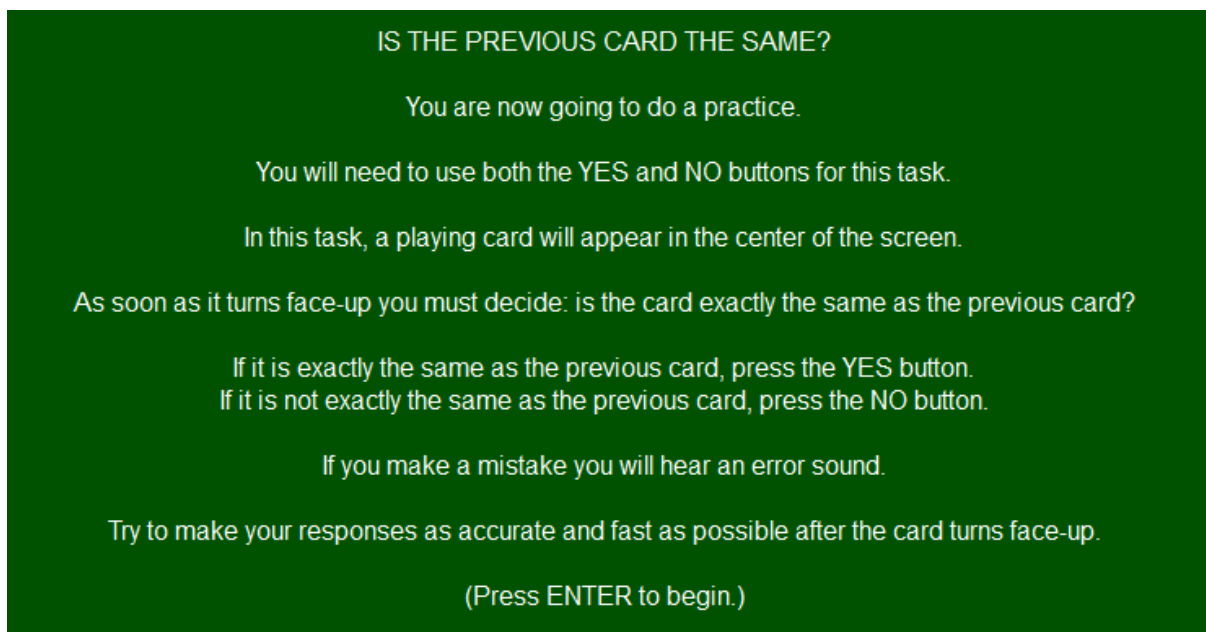


#### **Task four - A One-Back task (working memory).**<sup>[3,5,28,29]</sup>

- The working memory task requires the person to maintain information, over a short time.
- The individual is faced with a single and simple question “is this card the same as that on the immediately previous trial?” the “yes” or “no” key must be pressed as fast as possible each time the card appears.
- The task ends after 30 trials and all anticipatory responses are excluded.

In Figure 2.5 is the screenshot of how the instructions for task four were presented to participants on the computer screen during Cogstate sport baseline testing.

*Figure 2.5 – A screenshot of the instructions for task three in the Cogstate test.*



**Time allocation:**

The test took an estimated time of 30 to 40 min to complete. This time frame included two practice trials and the actual baseline test.

**Data scoring:**

All results are measured in milliseconds to indicate response speed and by a number of errors to assess accuracy.

The Cogstate battery can be quantified into a single score by means of the standard data extract. The four task's composite scores need to be computed into the extract. The quantification of these scores had been provided by the Science director (Adrian Schembri) of the research division at Cogstate in Melbourne, Australia via e-mail correspondence (Appendix K).

**The units of measurement for the four tasks were as follow:**

- A detection task (psychomotor function)
  - Reaction time was measured in milliseconds (speed), which was then normalized using a logarithmic base transformation (Log10 ).
- An identification task (visual attention)
  - Reaction time was measured in milliseconds (speed), which was then normalized using a logarithmic base transformation (Log10 ).
- A one card learning task (visual learning).
  - The proportion of correct answers was the performance measure thus accuracy was evaluated. This was normalized using an arcsine square root transformation.
- A one-back task (working memory).
  - The proportion of correct answers was the performance measure thus accuracy was evaluated. This was normalized using an arcsine square root transformation.

### 3.3.4.2 The King-Devick (KD) test

The following equipment and procedure was followed when the KD test was administered.

#### Equipment used:

- The King-Devick test cards
- Pencils
- Eraser
- Quiet room with limited distractors (e.g. people moving or talking, music or televisions) for a baseline.
- Stopwatch

#### Administration of test:

The KD test requires participants to read a series of single digit numbers out loud,<sup>[2,19,30,31,32,37]</sup> without using a finger or a pointer.<sup>[27]</sup> The numbers are read from left to right and top to bottom, the same as normal reading patterns.<sup>[31,32,37]</sup> The numbers are uniquely spaced for each card and increases in difficulty.<sup>[34]</sup> The main goal is that the participant read out the numbers as swiftly as possible without any errors.<sup>[2,19,31,32]</sup>

The participant is provided with one practice card which is not counted.<sup>[31,32,37]</sup> The practice card is then followed by three consecutive cards.<sup>[31,32,34,37]</sup> An example of the three test cards and the single practice card can be seen in Figure 2.7 (Appendix L). The participant must read each card as fast as possible.<sup>[31,32]</sup> Any immediate self-corrections are not counted as errors.<sup>[31,32,37]</sup> Any errors not corrected requires the participant to re-start the test.<sup>[31,32,37]</sup> A maximum of three attempts per card is permitted before continuing with the next card.<sup>[31,32,37]</sup> In the end, the sum of the time taken of all three cards is recorded along with a number of errors. The fastest time without errors is then used as the baseline.<sup>[19,31,32,37]</sup>

#### Time allocation:

The test was fairly simple and took only one to two minutes to complete per individual.

#### Data scoring:

In the end, the timed sum of all three cards was recorded, in seconds, along with a number of errors. The fastest time without errors was then used as the baseline.

### 3.3.5 Statistical analysis

The raw data from this study was captured in Excel 2013 and converted into a STATA 14 format before detailed analysis. All the statistical analyses were done by Mr. C. Janse van Rensburg, from the bio stats unit, South African Medical research council (Appendix M).

The **first objective** was to determine and quantify changes in baseline values for the KD test and Cogstate sport test for all the involved participants measured at the start of the 2016 and 2017 sports season.

- The descriptive statistics mean, median, standard deviation and inter-quartile range were used to describe the test scores from the KD and Cogstate test.

The **second objective** was to determine the significance of the difference between the 2016 and 2017 baseline values, including test-retest reliability in both the KD test and Cogstate Sport tests.

- The **T-test** was used for the Cogstate sport test to determine if there were any statistically significant differences between baseline values from 2016 to 2017 for all four tasks of the Cogstate sport test.
- The **Kruskal-Wallis non-parametric** test was used for the KD test, as an alternative to the T-tests because there was an outlier which it could accommodate for.
- For both the KD test and the Cogstate sport test the **effect sizes (Cohen's D)** were calculated for the differences found between 2016 and 2017 baseline data. This score is used to indicate the standardised difference between two groups and helps to evaluate the differences found. The values can be interpreted from a clinical perspective as follow; 0.2 or less = Small; between 0.3 and 0.5 = Medium; between 0.6 and 0.8 = Large; and 0.9+ = Very large.<sup>[40]</sup>
- The **interclass correlation coefficient (ICC)** was used to determine the test re-test reliability of baseline values from two consecutive years. The values can be interpreted from a clinical perspective as follow; less than 0.40 = poor; between 0.40 and 0.59 = low; between 0.60 and 0.69 = marginal; 0.7 and 0.79 = adequate; between 0.8 and 0.89 = good; and 0.9 and more = excellent.<sup>[4]</sup>

The **third objective** was to determine if differences in baseline values with respect to sex and age observed in objective one were statistically significant for the KD test and Cogstate sport test.

- The **Kruskal-Wallis non-parametric** test was used for the KD test and the Cogstate sport test, as an alternative to the T-tests because sample sizes within combinations of sex and year of birth were too small.
- The **Two-way ANOVA** was used to determine if there were any statistically significant differences between baseline values from 2016 to 2017 for all four tasks of the Cogstate sport test.

The null hypothesis, for both the KD test and the Cogstate sport test, would be that there is no significant difference between to specified variables. If the significance value is less than 0.05, the null hypothesis can be rejected. The only exception was the Cogstate sport test, in the statistical analysis for objective two (Table 4.15) The Bonferroni correction was used, and the p-value was adjust to 0.0125 to accommodate for the multiple testing of all four tasks.

The non-parametric test were used to accommodate for the highly individulized data collected. The non-parametric tests can interpret data that doesn't follow a normal distrubution, which was clearly the case when it came to individual cognitive ability.

### **3.3.5.1 Sample size**

Baseline data were collected from (108 for the KD test and 112 for the Cogstate Sport) high school athletes between the ages of 13 and 18 both male and female, from a large Pretoria-based high school (Hoërskool Waterkloof). The data was captured during 2016 and 2017 by the researcher, Ms. J. Coetzer, as part of her duties running an existing concussion clinic at the school.

# Chapter 4 – Results

## 4.1 Introduction

This chapter will list all the study results and statistics for the KD test and Cogstate sports test for each of the study objectives.

## 4.2 The study aim and objectives.

The main aim of this study was to investigate and report the difference in concussion baseline values from one sports season to the next. These results were used to determine test-retest reliability indicating the merit of using a year old baseline test, should a more recent test not be available.

### Objectives

1. The first objective was to determine and quantify changes in baseline values for the KD test and Cogstate sport test for all the involved participants measured at the start of the 2016 and 2017 sports season.
2. The second objective was to determine the significance of the difference between the 2016 and 2017 baseline values, including test-retest reliability in both the KD test and Cogstate Sport tests.
3. The third objective was to determine if differences in baseline values with respect to sex and age observed in objective one were statistically significant for the KD test and Cogstate sport test.

## 4.3 Chapter flow

In this chapter, all the statistical analysis will be showed and labelled in a logical sequence as it remains to be discussed in Chapter 5. This section will show the demographical summary, statistical analysis, Tables and Figures for both the KD (4.2) test and the Cogstate (4.3) test, per individual objective.

## 4.4 The King-Devick test

The following results all pertain to the KD test and the statistical analysis done for objective one, two and three.

### 4.4.1 Demographic summary of participants

Baseline data were collected from 108 participants. All participants were high school athletes between the ages of 13 and 18, both male and female were included, from a large Pretoria-based high school (Hoërskool Waterkloof) in South Africa.

Table 4.1 describes the overall number of participants for the KD test, with regards to sex and age. There were a total of 108 participants of which 48 were female and 60 were male. The variables sex and age groups were described using frequencies and proportions.

*Table 4.1 – The King Devick participant summary for participants in both 2016 and 2017.*

Birth Year	Female	male	Total
1999 ( '16 – gr11)( '17 – gr12) (Age: 16 – 18 yrs.)	9	7	16 (14.81%)
2000 ( '16 – gr10)( '17 – gr11) (Age: 15 – 17 yrs.)	7	9	16 (14.81%)
2001 ( '16 – gr9)( '17 – gr10) (Age: 14 – 16 yrs.)	5	22	27 (25%)
2002 ( '16 – gr8)( '17 – gr9) (Age: 13 – 15 yrs.)	27	22	49 (45.37%)
Total (gr8 – gr12) (Age: 13 – 18 yrs.)	48 (44.44%)	60 (55.55%)	108

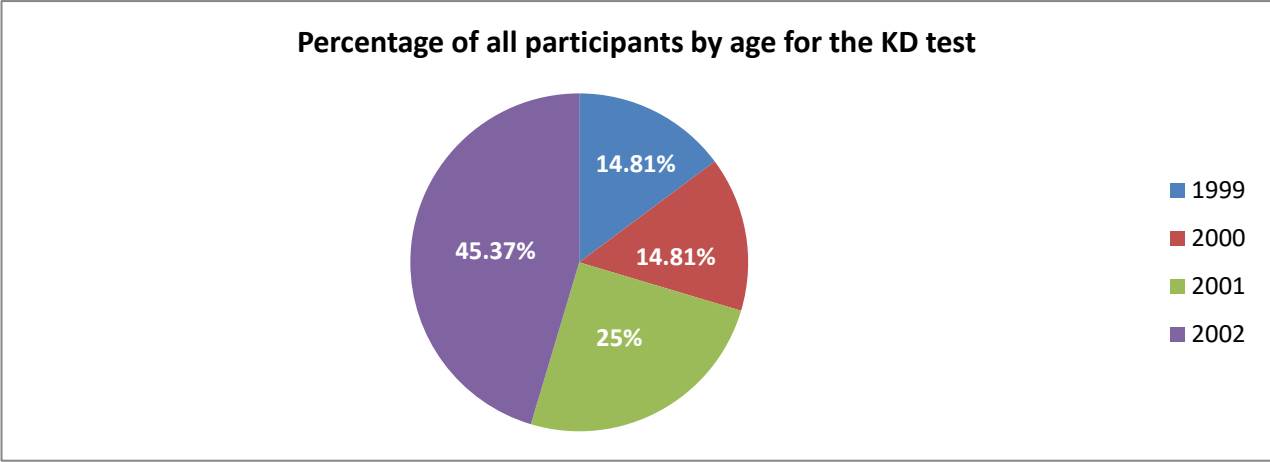
*Gr – Grade in school; yrs. – Age in years; '16 – 2016; '17 – 2017.*

In Table 4.1 the male participant group consist of 55.55% and the female participants 44.44% of the total number of participants. The youngest age group was the most prevalent; those born in 2002 (Age: 13 – 15 yrs.) made up 45.37% of all the participants.

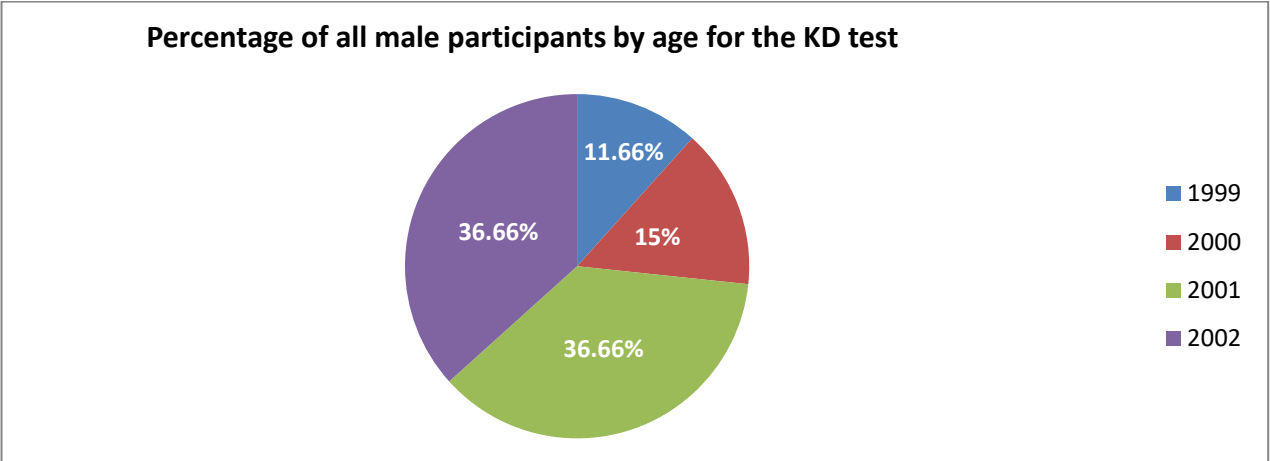


Figure 4.1 to Figure 4.3 were used to depict the percentage of participation from different sex and age groups for the KD test. These three pie charts will be discussed in Chapter five.

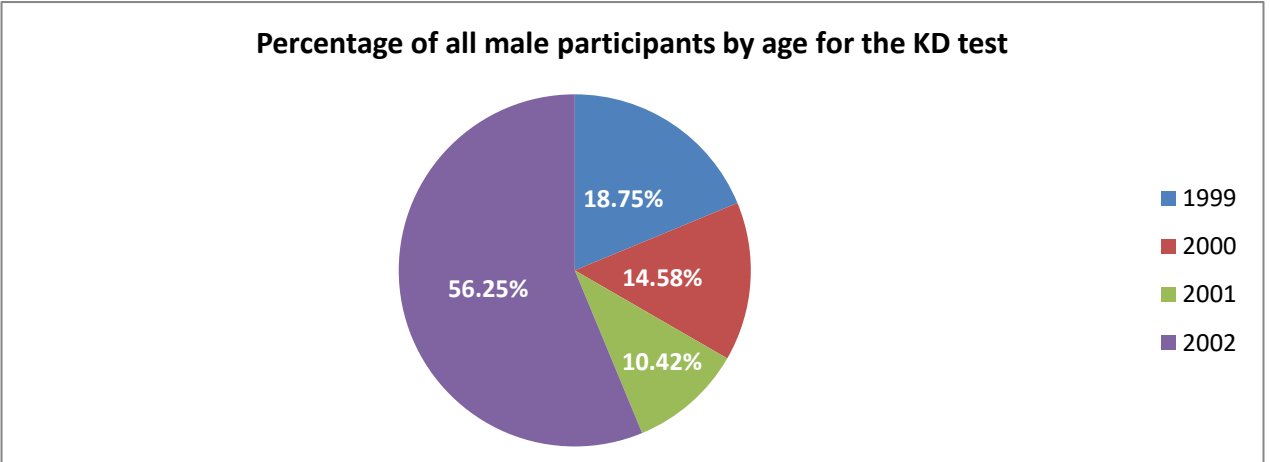
*Figure 4.1 – Percentage of total participants by year of birth for the KD test.*



*Figure 4.2 – Percentage of total male participants by year of birth for the KD test.*



*Figure 4.3 – Percentage of total male participants by year of birth for the KD test.*



## 4.4.2 Objective one

The first objective was to determine and quantify changes in baseline values for the KD test for all the involved participants measured at the start of the 2016 and 2017 sports season.

### 4.4.2.1 Statistical analyses

The descriptive statistics mean, median, standard deviation and inter-quartile range, were used to describe the test scores from the King-Devick (KD) test.

The KD test baseline value is a simple score, consisting of the total time it took to complete the three test cards, and it is measured in seconds. This means that a decrease in the total score, indicates a faster time and that is seen as an improvement in baseline values.<sup>[1,17,22,32]</sup>

### 4.4.2.2 Tables and Figures

Mean baseline values and the differences calculated between the 2016 and 2017 baseline values in the King-Devick test are summarized in the following Tables:

- *Table 4.2 – The descriptive statistics for the 2016 and 2017 KD baseline test values for males, females and the total group.*
- *Table 4.3 – The descriptive statistics for the 2016 and 2017 KD baseline test values for all the different age groups, regardless of sex.*
- *Table 4.4 – The descriptive statistics for the 2016 and 2017 KD baseline test values for all the different age groups in the **female** participant group.*
- *Table 4.5 – The descriptive statistics for the 2016 and 2017 KD baseline test values for all the different age groups in the **male** participant group.*

King Devick statistical data are summarized in the following graphs:

- *Figure 4.4 – A graph depicting the mean difference between the 2016 and 2017 baseline scores for the King-Devick test by sex and year group.*

### 4.4.2.3 Results

Table 4.2 shows the descriptive results for the difference between 2016- and 2017 baseline values for male participants, female participants and the total group that participated in the KD test.

*Table 4.2 – The descriptive statistics for the 2016 and 2017 KD baseline test values for males, females and the total group.*

Sex	Variable	KD 2016	KD 2017	KD difference
Female (gr8 – gr12) (Age: 13 -18 yrs.)	N	48.00	48.00	48.00
	Min	35.00	30.00	-55.00
	Max	110.00	60.00	8.00
	<b>Mean</b>	<b>48.06</b>	<b>45.85</b>	<b>-2.21</b>
	SD	11.34	6.90	9.17
	Median	46.50	45.00	-0.85
	IQR	11.00	9.87	5.44
Male (gr8 – gr12) (Age: 13 -18 yrs.)	N	60.00	60.00	60.00
	Min	33.00	30.00	-16.88
	Max	70.00	64.00	10.40
	<b>Mean</b>	<b>49.98</b>	<b>46.31</b>	<b>-3.67</b>
	SD	7.46	6.07	5.57
	Median	49.00	45.61	-3.17
	IQR	9.00	7.56	6.00
Total (gr8 – gr12) (Age: 13 -18 yrs.)	N	108.00	108.00	108.00
	Min	33.00	30.00	-55.00
	Max	110.00	64.00	10.40
	<b>Mean</b>	<b>49.13</b>	<b>46.11</b>	<b>-3.02</b>
	SD	9.38	6.42	7.38
	Median	48.00	45.42	-2.00
	IQR	9.50	8.16	6.00

*N – number of participants; Min – minimum (smallest) value; Max – maximum (biggest) value; Mean – value average; SD – standard deviation; Median (p50) – the 50% separation point for the upper half from the lower half of all the participants; IQR – inter quartile range; Gr – Grade in school; yrs. – Age in years; '16 – 2016; '17 – 2017.*

Table 4.2 shows that there was a decrease in the mean time for all participants, and for both male and females.

In Table 4.3 the results for the KD test is shown across the various age groups (year of birth, from 1999 to 2002) for the total group. The results show the difference between 2016- and 2017 baseline values amongst the different age groups, regardless of sex.

*Table 4.3 – The descriptive statistics for the 2016 and 2017 KD baseline test values for all the different age groups, regardless of sex.*

Age group	Variable	KD 2016	KD 2017	KD difference
1999 ( '16 – gr11)( '17 – gr12) (Age: 16 – 18 yrs.)	N	16.00	16.00	16.00
	Min	36.00	39.52	-11.00
	Max	56.00	50.99	9.25
	<b>Mean</b>	<b>46.25</b>	<b>45.40</b>	<b>-0.85</b>
	SD	5.60	3.49	5.40
	Median	46.50	45.00	-1.00
	IQR	7.00	4.45	7.00
2000 ( '16 – gr10)( '17 – gr11) (Age: 15 – 17 yrs.)	N	16.00	16.00	16.00
	Min	41.00	38.86	-8.00
	Max	60.00	60.00	3.00
	<b>Mean</b>	<b>49.13</b>	<b>47.46</b>	<b>-1.66</b>
	SD	5.82	5.87	3.71
	Median	49.00	45.20	-1.05
	IQR	8.00	8.74	5.04
2001 ( '16 – gr9)( '17 – gr10) (Age: 14 – 16 yrs.)	N	27.00	27.00	27.00
	Min	39.00	30.00	-16.88
	Max	66.00	57.16	1.44
	<b>Mean</b>	<b>49.56</b>	<b>44.93</b>	<b>-4.72</b>
	SD	7.64	6.32	4.89
	Median	47.00	45.77	-3.89
	IQR	10.00	7.12	5.00
2002 ( '16 – gr8)( '17 – gr9) (Age: 13 – 15 yrs.)	N	49.00	49.00	49.00
	Min	33.00	30.00	-55.00
	Max	110.00	64.00	10.40
	<b>Mean</b>	<b>49.84</b>	<b>46.60</b>	<b>-3.24</b>
	SD	11.87	7.33	9.55
	Median	49.00	47.00	-1.80
	IQR	11.00	10.00	5.00

*N – number of participants; Min – minimum (smallest) value; Max – maximum (biggest) value; Mean – value average; SD – standard deviation; Median (p50) – the 50% separation point for the upper half from the lower half of all the participants; IQR – inter quartile range; Gr – Grade in school; yrs. – Age in years; '16 – 2016; '17 – 2017.*

Table 4.3 shows a decrease in mean time for each age group, with the two youngest age groups (born in 2001 and 2002) showing the biggest difference.

In Table 4.4 the difference between 2016- and 2017 baseline values are shown according to age (year of birth, 1999 to 2002) for all female participants in the KD test.

*Table 4.4 – The descriptive statistics for the 2016 and 2017 KD baseline test values for all the different age groups in the **female** participant group.*

Female age group	Variable	KD 2016	KD 2017	KD difference
1999 ( '16 – gr11)( '17 – gr12) (Age: 16 – 18 yrs.)	N	9.00	9.00	9.00
	Min	40.00	40.46	-7.54
	Max	56.00	50.99	3.80
	<b>Mean</b>	<b>46.22</b>	<b>45.78</b>	<b>-0.44</b>
	SD	4.97	3.96	3.81
	Median	46.00	45.00	1.25
	IQR	5.00	6.20	4.09
2000 ( '16 – gr10)( '17 – gr11) (Age: 15 – 17 yrs.)	N	7.00	7.00	7.00
	Min	41.00	41.33	-8.00
	Max	58.00	53.47	3.00
	<b>Mean</b>	<b>48.00</b>	<b>46.37</b>	<b>-1.63</b>
	SD	6.32	4.51	4.64
	Median	47.00	44.00	0.33
	IQR	11.00	8.00	9.79
2001 ( '16 – gr9)( '17 – gr10) (Age: 14 – 16 yrs.)	N	5.00	5.00	5.00
	Min	39.00	35.11	-4.35
	Max	57.00	57.16	0.16
	<b>Mean</b>	<b>45.80</b>	<b>43.78</b>	<b>-2.02</b>
	SD	7.95	8.62	1.99
	Median	43.00	41.78	-1.22
	IQR	12.00	8.44	3.10
2002 ( '16 – gr8)( '17 – gr9) (Age: 13 – 15 yrs.)	N	27.00	27.00	27.00
	Min	35.00	30.00	-55.00
	Max	110.00	60.00	8.00
	<b>Mean</b>	<b>49.11</b>	<b>46.13</b>	<b>-2.98</b>
	SD	14.23	8.00	11.83
	Median	47.00	48.00	-1.00
	IQR	14.00	12.21	5.00

*N – number of participants; Min – minimum (smallest) value; Max – maximum (biggest) value; Mean – value average; SD – standard deviation; Median (p50) – the 50% separation point for the upper half from the lower half of all the participants; IQR – inter quartile range; Gr – Grade in school; yrs. – Age in years; '16 – 2016; '17 – 2017.*

Table 4.4 shows a decrease in mean time for each age group from the female participants, with the two youngest age groups (born in 2001 and 2002) showing the biggest difference.

In Table 4.5 the difference between 2016- and 2017 baseline values are shown according to age (year of birth, 1999 to 2002) for all male participants in the KD test.

*Table 4.5 – The descriptive statistics for the 2016 and 2017 KD baseline test values for all the different age groups in the male participant group.*

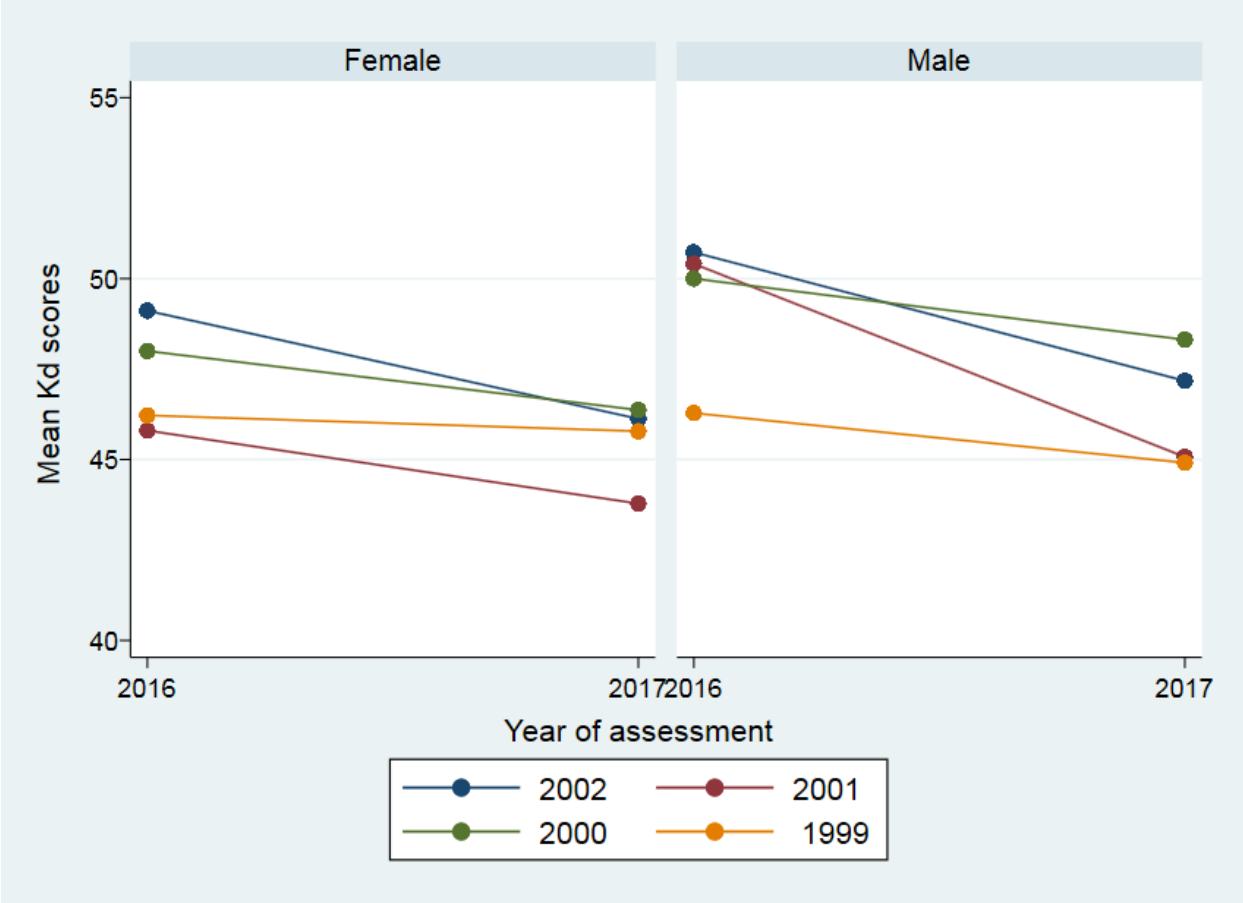
Year of birth	Variable	KD 2016	KD 2017	KD difference
1999 ( '16 – gr11)( '17 – gr12) (Age: 16 – 18 yrs.)	N	7.00	7.00	7.00
	Min	36.00	39.52	-11.00
	Max	55.00	48.61	9.25
	<b>Mean</b>	<b>46.29</b>	<b>44.91</b>	<b>-1.37</b>
	SD	6.75	3.00	7.27
	Median	47.00	45.00	-3.48
	IQR	12.00	4.00	12.61
2000 ( '16 – gr10)( '17 – gr11) (Age: 15 – 17 yrs.)	N	9.00	9.00	9.00
	Min	41.00	38.86	-8.00
	Max	60.00	60.00	2.00
	<b>Mean</b>	<b>50.00</b>	<b>48.31</b>	<b>-1.69</b>
	SD	5.61	6.89	3.11
	Median	49.00	45.40	-2.10
	IQR	5.00	9.34	4.34
2001 ( '16 – gr9)( '17 – gr10) (Age: 14 – 16 yrs.)	N	22.00	22.00	22.00
	Min	40.00	30.00	-16.88
	Max	66.00	56.00	1.44
	<b>Mean</b>	<b>50.41</b>	<b>45.07</b>	<b>-5.34</b>
	SD	7.49	5.92	5.17
	Median	48.00	45.89	-3.98
	IQR	9.00	7.12	8.77
2002 ( '16 – gr8)( '17 – gr9) (Age: 13 – 15 yrs.)	N	22.00	22.00	22.00
	Min	33.00	36.00	-14.95
	Max	70.00	64.00	10.40
	<b>Mean</b>	<b>50.73</b>	<b>47.17</b>	<b>-3.55</b>
	SD	8.36	6.56	5.93
	Median	51.50	47.00	-3.00
	IQR	11.00	9.00	6.00

*N – number of participants; Min – minimum (smallest) value; Max – maximum (biggest) value; Mean – value average; SD – standard deviation; Median (p50) – the 50% separation point for the upper half from the lower half of all the participants; IQR – inter quartile range; Gr – Grade in school; yrs. – Age in years; '16 – 2016; '17 – 2017.*

Table 4.5 shows a decrease in mean time for each age group from the male participants, with the two youngest age groups (born in 2001 and 2002) showing the biggest difference.

Figure 4.4 depicts the mean difference in baseline values for the KD test from 2016 to 2017. As seen in Figure 4.1 the decline in values indicates that both sexes and each age group recorded a faster time in 2017 than in 2016 for the KD test. The two youngest age groups (2002 and 2001) in both the male and female participants showed the biggest decrease in baseline values from 2016 to 2017. The decrease in the time it took to complete a baseline is seen as an improvement because less time was taken to successfully complete baseline testing.

Figure 4.4 – A graph depicting the mean difference between the 2016 and 2017 baseline scores for the King-Devick test by sex and year group.



### 4.4.3 Objective two

The second objective was to determine the significance of the difference between the 2016 and 2017 baseline values, including test-retest reliability in the KD test.

#### 4.4.3.1 Statistical analyses

Differences calculated between the 2016 and 2017 KD baseline values are reported in Table 4.2 to Table 4.5. Three main statistical tests were used to analyse the KD test data for objective two.

Firstly, to accommodate the outlier the **non-parametric Kruskal-Wallis test** was used to determine the statistical significant of the difference between values of the two consecutive years. The null hypothesis would be that there is no significant difference between the specified variables. If the significance value is less than 0.05, the null hypothesis can be rejected.

Secondly, the **effect size (Cohen's D)** was calculated for the difference between 2016 and 2017 KD baseline test scores. This score is used to indicate the standardised difference between two groups and helps to evaluate the differences found. The values can be interpreted from a clinical perspective as follow; 0.2 or less = Small; between 0.3 and 0.5 = Medium; between 0.6 and 0.8 = Large; and 0.9+ = Very large.<sup>[41]</sup> A positive value represents an improvement and a negative value represents a worsening on the baseline values from 2016 to 2017.

And thirdly, the **interclass correlation coefficient (ICC)** was used to determine the reliability of baseline values from two consecutive years. The values can be interpreted from a clinical perspective as follow; less than 0.40 = poor; between 0.40 and 0.59 = low; between 0.60 and 0.69 = marginal; 0.7 and 0.79 = adequate; between 0.8 and 0.89 = good; and 0.9 and more = excellent.<sup>[4]</sup>

#### 4.4.3.2 Tables and Figures

The KD test statistical data are summarized in the following Tables:

- *Table 4.6 – Kruskal-Wallis non-parametric test results; Comparison between 2016 and 2017 KD baseline test values for the total participant group.*



- *Table 4.7 – Effect sizes based on the comparison between mean 2016 and 2017 KD results for the total participant group.*
- *Table 4.8 – The interclass correlation coefficient between 2016 and 2017 baseline scores for the KD test for the total participant group.*

#### 4.4.3.3 Results

In Table 4.6 the Kruskal-Wallis non-parametric test was used to test for the difference between baseline values from 2016 to 2017 in the KD test for all participants. The p - value ( $p < 0.0001$ ) indicates that there is a statistically significant difference between 2016 and 2017 KD values for the group overall.

*Table 4.6 – Kruskal-Wallis non-parametric test results; Comparison between 2016 and 2017 KD baseline test values for the total participant group.*

p - Value	Significance of value	Null hypothesis
<b>0.0001*</b>	< 0.05	Rejected, indicates a statistical significant difference.

*\*: significant different*

In Table 4.7 the effect size (Cohen's D) value of 0.38 (0.12 – 0.64), indicates a small – medium effect size for the difference between 2016 to 2017 baseline values.

*Table 4.7 – Effect sizes based on the comparison between mean 2016 and 2017 KD results for the total participant group.*

Effect size	Estimate	95% Confidence Interval
Cohen's D	<b>0.38</b>	1.12 - 0.64

In Table 4.8 the ICC value of 0.54 (0.36 – 0.68) shows a fairly low correlation between 2016 and 2017 baseline data when taking into account all the participants for the KD test.

*Table 4.8 – The interclass correlation coefficient between 2016 and 2017 baseline scores for the KD test for the total participant group.*

KD	ICC	95% Confidence Interval
Individual	<b>0.54</b>	0.36 - 0.68

## 4.2.4 Objective three

The third objective was to determine if differences in baseline values with respect to sex and age observed in objective one were statistically significant for the KD test.

### 4.2.4.1 Statistical analyses

The Kruskal-Wallis non-parametric test was used as an alternative to the T-tests and ANOVA test. The sub-group sizes for age and sex were small and there was an outlier that had an influence on the T-tests and ANOVA test that caused the tests to be less reliable. The Kruskal-Wallis non-parametric tests compensated for the group sizes and the outlier.

The null hypothesis would be that there is no significant difference between the specified variables. If the significance value is less than 0.05, the null hypothesis can be rejected.

### 4.2.4.2 Tables and Figures

King Devick statistical data are summarized in the following Tables:

- *Table 4.9 – Kruskal-Wallis non-parametric test results; Comparison between 2016 and 2017 KD baseline test values for; the different age groups, and the male- and female participant groups.*

### 4.2.4.3 Results

In Table 4.9 the Kruskal-Wallis non-parametric test results for the total groups, sex and various age groups for the KD test are presented.

*Table 4.9 – Kruskal-Wallis non-parametric test results; Comparison between 2016 and 2017 KD baseline test values for; the different age groups, and the male- and female participant groups.*

	p - value	Significance value	Null hypothesis
Born in 1999 (‘16 – gr11)(‘17 – gr12) (Age: 16 – 18 yrs.)	0.63	> 0.05	Can’t be rejected, indicates no statistically significant difference.
Born in 2000 (‘16 – gr10)(‘17 – gr11) (Age: 15 – 17 yrs.)	0.75	> 0.05	Can’t be rejected, indicates no statistically significant difference.
Born in 2001 (‘16 – gr9)(‘17 – gr10) (Age: 14 – 16 yrs.)	0.17	> 0.05	Can’t be rejected, indicates no statistically significant difference.
Born in 2002 (‘16 – gr8)(‘17 – gr9) (Age: 13 – 15 yrs.)	0.04*	< 0.05	Rejected, indicates a statistical significant difference.
Male participants (gr 8 – gr12) (Age: 13 – 18 yrs.)	0.29	> 0.05	Can’t be rejected, indicates no statistically significant difference.
female participants (gr 8 – gr12) (Age: 13 – 18 yrs.)	0.74	> 0.05	Can’t be rejected, indicates no statistically significant difference.

\*: *significant different*

Table 4.9 shows that there is a statistically significant difference between baseline values from 2016 to 2017 for the whole participant group, and the youngest age group (2002). There was no statistically significant difference within the other three age groups (2001, 2000, and 1999) or within the male and female groups.

## 4.2.5 The summary of all the results for the KD test.

In Table 4.10 the summarized trends and interpretation thereof are shown for each objective for the KD test.

*Table 4.10 – A summary of all the KD test results for each objective.*

Objective one - to determine and quantify changes in baseline values for the KD test for all the involved participants measured at the start of the 2016 and 2017 sports season.				
Variable	Trend	Table	Direction	Interpretation
<i>Males, females and the total group.</i>	Yes	4.2	Decrease in mean value	Improvement by all participants
<i>All the different age groups.</i>	Yes	4.3	Decrease in mean value	Youngest groups showed biggest improvement
<i>Different age groups in the female participant group.</i>	Yes	4.4	Decrease in mean value	Each age group improved, the youngest improved most
<i>Different age groups in the male participant group.</i>	Yes	4.5	Decrease in mean value	Each age group improved, the youngest improved most
Objective two - to determine the significance of the difference between the 2016 and 2017 baseline values, including test-retest reliability of the KD test.				
<i>Kruskal-Wallis non-parametric test results for the total participant group.</i>	Yes (p = 0.0001)	4.6		Statistically significant difference found
<i>Effect sizes for the total participant group.</i>	Cohen's D:0.38	4.7		Small to medium effect
<i>The ICC value between 2016 and 2017 baseline scores for the total participant group.</i>	0.54	4.8		Low test re-test reliability
Objective three - to determine if differences in baseline values with respect to sex and age observed in objective one were statistically significant for the KD test.				
<i>Kruskal-Wallis non-parametric test results for the different age groups, male- and female participant groups, and for the total group as well.</i>	Born 1999 (p = 0.63) Born in 2000 (p = 0.75) Born in 2001 (p = 0.168) Born in 2002 (p = 0.043) Males (p = 0.29) Females (p = 0.74)	4.9	Decrease in mean value	There was no statistically significant difference between males and females or for the three oldest age groups. There was a statistically significant difference for the youngest age group.

## 4.5 Cogstate Sport test

The following results all pertain to the Cogstate test and the statistical analysis done for objective one, two and three.

### 4.5.1 Demographic summary of participants

Baseline data were collected from 112 participants between the ages of 13 and 18, both male and female, from a large Pretoria-based high school (Hoërskool Waterkloof) in South Africa. The data was captured during the pre-season (February and March) for the 2016 and 2017 sport season.

Table 4.10 describes the overall number of participants for the Cogstate test, with regards to sex and age. There were a total of 112 participants of which 44 were female and 68 were male.

*Table 4.11 – The Cogstate sport participant summary for participants in both 2016 and 2017.*

Birth Year	Female	male	Total
1999 ( '16 – gr11)( '17 – gr12) (Age: 16 – 18 yrs.)	8	8	16 (14.28%)
2000 ( '16 – gr10)( '17 – gr11) (Age: 15 – 17 yrs.)	6	10	16 (14.28%)
2001 ( '16 – gr9)( '17 – gr10) (Age: 14 – 16 yrs.)	6	24	30 (26.78%)
2002 ( '16 – gr8)( '17 – gr9) (Age: 13 – 15 yrs.)	24	26	50 (44.64%)
Total (gr 8 – gr12) (Age: 13 – 18 yrs.)	44(39.28%)	68 (60.71%)	112

*Gr – Grade in school; yrs. – Age in years; '16 – 2016; '17 – 2017.*

In Table 4.10 the male participants group consisted of 60.71% and the female participants 39.28% of the total participants group. The youngest age group was the most prevalent, those born in 2002 (Age: 13 – 15 yrs.) made up 44.64% of all the participants.

Figure 4.5 to Figure 4.7 show the percentage of participation from different sex and age groups for the Cogstate sport test. These three pie charts are discussed in the demographic summary in Chapter five.

Figure 4.5 – Percentage of total participants by year of birth for the Cogstate test.

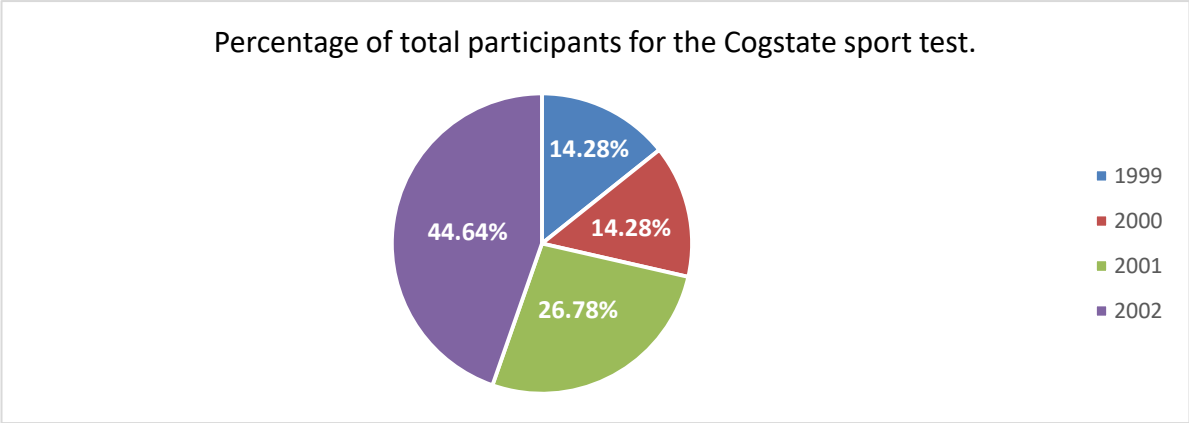


Figure 4.6 – Percentage of total male participants by year of birth for the Cogstate test.

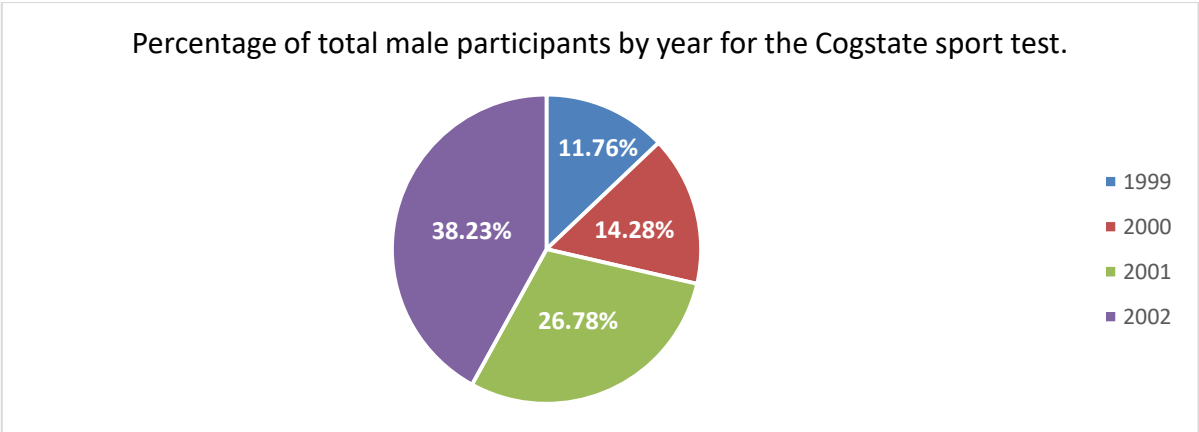
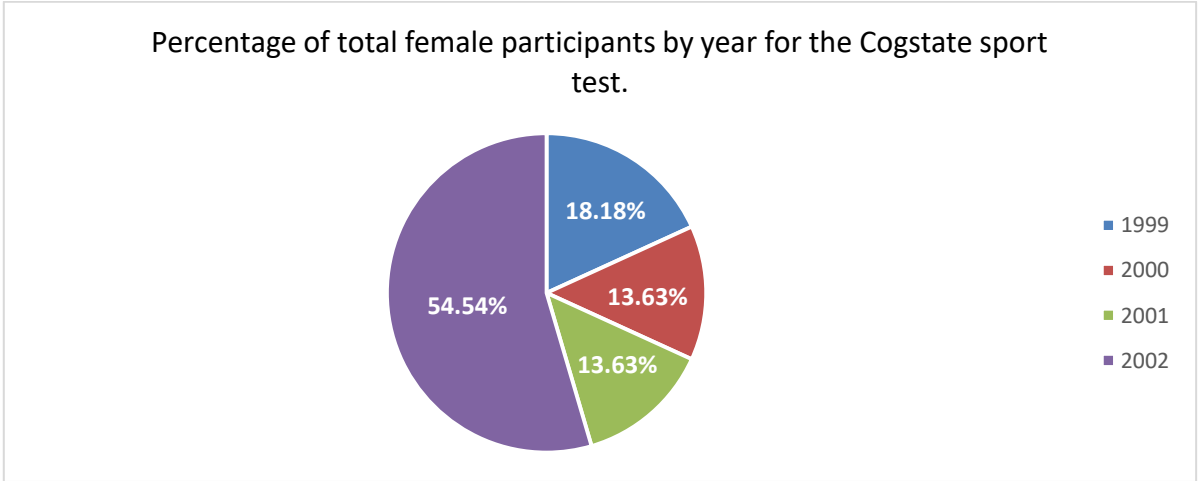


Figure 4.7 – Percentage of total female participants by year of birth for the Cogstate test.



## 4.5.2 Objective one

The first objective was to determine and quantify changes in baseline values for Cogstate sport test for all the involved participants (112) at the start of the 2016 and 2017 sports season.

### 4.5.2.1 Statistical analyses

The descriptive statistics mean, median, standard deviation and inter-quartile range were used to describe the test scores from the Cogstate sport test for each of these four tasks (labelled by number in the Table 4.11 to Table 4.14)

Task one is a detection task (psychomotor function) and task two is an identification task (visual attention). Both were measured by reaction time, measured in milliseconds (speed), which was then normalized using a logarithmic base transformation (Log 10).

Task three is a one card learning task (visual learning) and task four is a one-back task (working memory). Both were measured by the proportion of the number of correct answers given, performance thus measures the accuracy. This was normalized using an arcsine square root transformation.

For the Cogstate test, a low numerical value is considered bad while a higher numerical value is considered good. Thus an improvement would be seen as an increase in total numerical value and a worsening or decline in value would be seen in the decrease in total numerical value.

### 4.5.2.2 Tables and Figures

Cogstate sport test descriptive data are summarized in the following Tables:

- *Table 4.12 – The descriptive statistics for the 2016 and 2017 Cogstate sport baseline test values for males, females and the total group.*
- *Table 4.13 – The descriptive statistics for the 2016 and 2017 Cogstate sport baseline test values for all the different age groups, regardless of sex.*

- *Table 4.14 – The descriptive statistics for the 2016 and 2017 Cogstate sport baseline test values for all the different age groups in the **female** participant group.*
- *Table 4.15 – The descriptive statistics for the 2016 and 2017 Cogstate sport baseline test values for all the different age groups in the **male** participant group.*



### 4.5.2.3 Results

In Table 4.12 the results for the difference between 2016- and 2017 baseline values for the tasks in the Cogstate sport test are shown for both sexes (male and female) across all ages. Included are the results for the following tasks: Task 1 (A detection task - psychomotor function), Task 2 (An identification task - visual attention), Task 3 (A one card learning - task visual learning), and Task 4 (A one-back task - working memory) are reported.

*Table 4.12 – The descriptive statistics for the 2016 and 2017 Cogstate sport baseline test values for males, females and the total group.*

Sex	variable	2016				2017				Difference			
		Task 1	Task 2	Task 3	Task 4	Task 1	Task 2	Task 3	Task 4	Task 1	Task 2	Task 3	Task 4
Female (gr 8 – gr12) (Age: 13 – 18 yrs.)	N	44.00	44.00	44.00	44.00	43.00	41.00	44.00	44.00	43.00	41.00	44.00	44.00
	Min	59.70	77.60	79.90	68.50	31.40	70.70	75.00	59.40	-57.30	-18.50	-27.00	-35.90
	Max	103.00	109.50	126.50	111.10	106.20	103.40	134.90	106.20	11.60	13.00	27.90	14.50
	Mean	88.61	93.78	106.98	90.99	84.46	90.54	105.62	88.21	-4.53	-3.27	-1.36	-2.78
	SD	8.91	7.76	9.94	8.92	11.29	7.80	10.71	10.31	10.52	7.52	13.26	9.69
	Median	90.55	94.00	107.85	91.20	86.90	90.60	107.30	88.80	-5.10	-5.40	-3.60	-3.70
	IQR	10.10	9.90	12.75	10.65	9.30	11.20	8.55	15.95	10.70	10.00	16.50	12.85
Male (gr 8 – gr12) (Age: 13 – 18 yrs.)	N	67.00	68.00	68.00	68.00	67.00	68.00	68.00	68.00	66.00	68.00	68.00	68.00
	Min	62.60	66.90	11.01	71.60	35.40	73.40	75.90	70.70	-61.10	-19.50	-18.50	-18.50
	Max	103.90	108.70	126.50	111.80	99.60	108.00	134.80	117.90	23.90	96.29	20.20	20.20
	Mean	87.07	91.54	101.26	91.72	84.34	90.19	104.28	91.64	-2.71	-1.35	3.02	-0.08
	SD	9.46	8.07	14.23	7.95	10.90	7.33	10.36	9.10	12.55	16.21	7.12	7.12
	Median	89.60	91.70	102.70	91.85	86.00	91.20	104.10	91.50	-1.95	2.35	-0.55	-0.55
	IQR	15.10	10.05	11.50	8.15	13.50	9.00	12.75	13.05	12.50	16.00	8.30	8.30
Total (gr 8 – gr12) (Age: 13 – 18 yrs.)	N	111.00	112.00	112.00	112.00	110.00	109.00	112.00	112.00	109.00	109.00	112.00	112.00
	Min	59.70	66.90	11.01	68.50	31.40	70.70	75.00	59.40	-61.10	-19.50	-27.00	-35.90
	Max	103.90	109.50	126.50	111.80	106.20	108.00	134.90	117.90	23.90	17.30	96.29	20.20
	Mean	87.68	92.42	103.51	91.43	84.39	90.32	104.81	90.29	-3.43	-2.07	1.30	-1.14
	SD	9.23	7.99	12.98	8.31	11.00	7.48	10.47	9.70	11.77	7.67	15.21	8.29
	Median	89.90	92.60	104.50	91.75	86.10	90.70	105.00	90.25	-2.40	-2.50	0.55	-0.95
	IQR	11.50	9.95	11.10	8.90	10.60	9.80	11.80	14.10	11.00	10.20	16.45	9.45

*N – number of participants; Min – minimum (smallest) value; Max – maximum (biggest) value; Mean – value average; SD – standard deviation; Median (p50) – the 50% separation point for the upper half from the lower half of all the participants; IQR – inter quartile range; Gr – Grade in school; yrs. – Age in years; '16 – 2016; '17 – 2017.*

In Table 4.12 the female participants showed a decrease (a worsening) in all four tasks. While the male participants and the total group showed a worsening in all but task three (visual learning), in which there was a slight increase (improvement) in the score.

In Table 4.13 the results for the difference between 2016- and 2017 baseline values in the Cogstate sport test are shown for the different age groups, regardless of sex. Included are the results for the following tasks: Task 1 (A detection task - psychomotor function), Task 2 (An identification task - visual attention), Task 3 (A one card learning - task visual learning), and Task 4 (A one-back task - working memory) are reported.

*Table 4.13 – The descriptive statistics for the 2016 and 2017 Cogstate sport baseline test values for all the different age groups, regardless of sex.*

Age groups	Variables	2016				2017				Difference			
		Task 1	Task 2	Task 3	Task 4	Task 1	Task 2	Task 3	Task 4	Task 1	Task 2	Task 3	Task 4
1999 (‘16 – gr11)(‘17 – gr12) (Age: 16 – 18 yrs.)	N	15.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	15.00	16.00	16.00	16.00
	Min	64.60	66.90	87.50	76.50	70.20	80.20	89.90	75.10	-12.80	-14.50	-12.10	-10.40
	Max	98.60	104.30	125.30	100.70	96.90	102.60	134.90	106.20	8.80	17.30	27.50	8.60
	Mean	<b>88.64</b>	<b>90.16</b>	<b>105.79</b>	<b>92.78</b>	<b>87.55</b>	<b>91.81</b>	<b>110.49</b>	<b>93.70</b>	<b>-0.75</b>	<b>1.65</b>	<b>4.70</b>	<b>0.92</b>
	SD	8.62	10.68	9.44	7.33	6.47	6.12	11.16	9.25	6.48	9.26	12.91	8.52
	Median	91.00	90.25	105.05	95.05	89.00	91.85	110.20	95.75	0.80	2.90	0.00	1.95
	IQR	10.50	15.85	10.70	8.50	8.55	7.90	9.30	12.70	13.00	14.60	21.55	6.30
2000 (‘16 – gr10)(‘17 – gr11) (Age: 15 – 17 yrs.)	N	16.00	16.00	16.00	16.00	15.00	15.00	16.00	16.00	15.00	15.00	16.00	16.00
	Min	59.70	77.60	81.30	68.50	64.20	81.20	75.00	72.90	-23.50	-6.70	-27.00	-16.60
	Max	100.30	101.10	108.30	111.80	98.40	106.80	115.80	117.90	15.20	13.00	15.80	11.40
	Mean	<b>83.04</b>	<b>90.22</b>	<b>97.86</b>	<b>93.10</b>	<b>84.33</b>	<b>92.09</b>	<b>98.76</b>	<b>92.24</b>	<b>1.51</b>	<b>2.33</b>	<b>0.90</b>	<b>-0.86</b>
	SD	11.92	7.31	8.30	9.80	12.21	7.29	11.50	10.75	9.05	6.34	12.87	6.99
	Median	86.05	91.25	101.30	94.85	88.80	91.90	102.00	92.55	1.50	0.60	4.85	-1.35
	IQR	17.65	12.35	10.50	10.00	23.00	9.10	8.20	12.70	9.00	9.90	16.15	8.20
2001 (‘16 – gr9)(‘17 – gr10) (Age: 14 – 16 yrs.)	N	30.00	30.00	30.00	30.00	30.00	29.00	30.00	30.00	30.00	29.00	30.00	30.00
	Min	62.60	70.80	91.20	73.60	31.40	77.20	76.90	75.40	-57.30	-19.50	-24.60	-13.50
	Max	96.40	108.70	120.00	107.70	99.60	100.70	118.70	104.00	23.90	11.50	19.60	16.10
	Mean	<b>83.45</b>	<b>90.64</b>	<b>102.11</b>	<b>91.42</b>	<b>82.60</b>	<b>90.62</b>	<b>102.02</b>	<b>91.90</b>	<b>-0.85</b>	<b>0.20</b>	<b>-0.09</b>	<b>0.48</b>
	SD	8.61	7.54	7.64	8.08	12.00	6.50	9.91	8.07	13.76	6.62	12.05	7.87
	Median	85.85	90.60	100.15	90.25	84.75	91.80	104.00	91.85	-0.65	1.90	1.90	1.75
	IQR	10.10	7.70	10.40	9.80	8.70	8.60	11.60	11.20	9.20	7.20	18.70	11.80
2002 (‘16 – gr8)(‘17 – gr9) (Age: 13 – 15 yrs.)	N	50.00	50.00	50.00	50.00	49.00	49.00	50.00	50.00	49.00	49.00	50.00	50.00
	Min	72.20	76.90	11.01	71.60	35.40	70.70	83.40	59.40	-61.10	-18.50	-24.40	-35.90
	Max	103.90	109.50	126.50	111.10	106.20	108.00	134.80	108.30	13.50	10.30	96.29	20.20
	Mean	<b>91.41</b>	<b>94.91</b>	<b>105.42</b>	<b>90.48</b>	<b>84.47</b>	<b>89.12</b>	<b>106.60</b>	<b>87.62</b>	<b>-7.34</b>	<b>-5.98</b>	<b>1.17</b>	<b>-2.86</b>
	SD	7.09	6.95	16.78	8.35	11.22	8.41	9.01	9.95	11.48	6.24	18.21	9.42
	Median	93.20	94.45	107.55	91.50	86.30	89.30	107.30	87.50	-7.00	-7.00	-2.30	-2.85
	IQR	6.20	8.70	11.20	9.30	11.10	11.00	11.20	12.50	9.00	7.80	16.60	11.00

*N – number of participants; Min – minimum (smallest) value; Max – maximum (biggest) value; Mean – value average; SD – standard deviation; Median (p50) – the 50% separation point for the upper half from the lower half of all the participants; IQR – inter quartile range; Gr – Grade in school; yrs. – Age in years; ‘16 – 2016; ‘17 – 2017.*

Table 4.13 indicates that both the two oldest age groups (1999 and 2000) showed a decrease (worsening) in only one task each. While the 2001 group showed a decrease in two tasks and the youngest (2002) showed a decrease in three tasks.

In Table 4.14 the results show the difference between 2016- and 2017 baseline values for female participants amongst the different age groups (year of birth, 1999 to 2002) in the Cogstate test. Included are the results for the following tasks: Task 1 (A detection task - psychomotor function), Task 2 (An identification task - visual attention), Task 3 (A one card learning - task visual learning), and Task 4 (A one-back task - working memory).

*Table 4.14 – The descriptive statistics for the 2016 and 2017 Cogstate sport baseline test values for all the different age groups in the **female** participant group.*

Year of birth	variable	2016				2017				Difference			
		Task 1	Task 2	Task 3	Task 4	Task 1	Task 2	Task 3	Task 4	Task 1	Task 2	Task 3	Task 4
1999 (‘16 – gr11)(‘17 – gr12) (Age: 16 – 18 yrs.)	N	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
	Min	82.70	84.20	87.50	84.40	82.40	84.30	89.90	75.10	-12.80	-14.50	-12.10	-10.40
	Max	98.60	104.30	115.80	100.70	96.90	102.60	134.90	106.20	4.80	7.30	27.50	5.50
	Mean	92.53	95.05	104.35	95.48	88.76	93.04	110.48	93.93	-3.76	-2.01	6.13	-1.55
	SD	5.00	7.22	8.69	5.47	5.06	6.09	14.99	9.81	6.04	7.38	15.57	6.34
	Median	93.30	97.10	104.05	96.55	89.00	93.05	108.40	95.75	-3.90	-1.35	0.00	-0.85
	IQR	5.65	11.65	9.70	6.50	7.50	8.85	19.10	11.70	9.65	10.10	28.30	11.00
2000 (‘16 – gr10)(‘17 – gr11) (Age: 15 – 17 yrs.)	N	6.00	6.00	6.00	6.00	6.00	5.00	6.00	6.00	6.00	5.00	6.00	6.00
	Min	59.70	77.60	85.90	68.50	64.20	83.20	75.00	72.90	-3.90	0.30	-27.00	-16.60
	Max	89.30	97.20	104.00	102.10	94.90	92.40	110.70	104.10	11.60	-3.90	15.80	11.40
	Mean	74.97	84.77	96.58	89.25	79.28	88.34	99.23	88.30	4.32	11.60	2.65	-0.95
	SD	12.15	7.26	6.86	12.29	12.74	3.60	12.35	11.27	5.17	4.32	15.30	9.87
	Median	77.40	83.20	97.50	81.40	81.40	89.00	102.00	87.90	5.45	5.17	7.15	5.00
	IQR	20.30	10.00	9.40	24.00	24.00	4.10	2.30	17.20	4.30	5.45	10.00	12.70
2001 (‘16 – gr9)(‘17 – gr10) (Age: 14 – 16 yrs.)	N	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	5.00	6.00	6.00
	Min	80.40	90.20	101.50	86.50	31.40	84.30	76.90	75.40	-57.30	-6.30	-24.60	-12.00
	Max	94.00	97.00	120.00	95.00	90.80	100.60	113.20	96.00	3.30	7.40	1.20	7.70
	Mean	86.77	93.53	109.85	90.12	76.03	94.06	97.10	87.60	-10.73	1.22	-12.75	-2.52
	SD	4.72	2.71	6.88	3.53	22.34	6.11	12.95	7.13	23.46	4.95	9.77	6.95
	Median	87.25	94.05	109.05	88.95	82.65	95.70	96.60	89.80	-0.70	1.90	-12.55	-4.05
	IQR	5.70	4.70	9.50	6.50	10.90	3.90	17.50	7.00	14.60	2.30	15.80	8.90
2002 (‘16 – gr8)(‘17 – gr9) (Age: 13 – 15 yrs.)	N	24.00	24.00	24.00	24.00	23.00	23.00	24.00	24.00	23.00	23.00	24.00	24.00
	Min	72.20	82.70	79.90	74.20	73.90	70.70	98.80	59.40	-13.60	-18.50	-18.50	-35.90
	Max	103.00	109.50	126.50	111.10	106.20	103.40	123.10	106.10	10.40	3.80	27.90	14.50
	Mean	91.17	95.67	109.74	90.14	86.51	89.39	107.73	86.43	-5.49	-6.71	-2.00	-3.71
	SD	6.50	7.63	10.03	9.76	6.86	9.07	5.82	10.78	5.96	6.18	11.20	11.37
	Median	92.20	94.65	109.85	89.30	87.80	89.30	107.30	86.20	-7.00	-7.00	-4.25	-3.85
	IQR	7.10	13.30	11.05	13.25	10.00	14.20	7.60	13.85	9.00	6.10	10.85	13.25

*N – number of participants; Min – minimum (smallest) value; Max – maximum (biggest) value; Mean – value average; SD – standard deviation; Median (p50) – the 50% separation point for the upper half from the lower half of all the participants; IQR – inter quartile range; Gr – Grade in school; yrs. – Age in years; ‘16 – 2016; ‘17 – 2017.*

Table 4.14 showed a decrease in all tasks for the youngest age group (2002). The 2001 group and, ironically, the oldest group (1999) showed a decrease in three tasks. The 2000 group had the best results, only two tasks showed a decrease.

In Table 4.15 the results show the difference between 2016- and 2017 baseline values for male participants amongst the different age groups (year of birth, 1999 to 2002) in the Cogstate test. Included are the results for the following tasks: Task 1 (A detection task - psychomotor function), Task 2 (An identification task - visual attention), Task 3 (A one card learning - task visual learning), and Task 4 (A one-back task - working memory). The results show the

*Table 4.15 – The descriptive statistics for the 2016 and 2017 Cogstate sport baseline test values for all the different age groups in the **male** participant group.*

Year of birth	variable	2016			2017			Difference					
		Task 2	Task 3	Task 4	Task 2	Task 3	Task 4	Task 2	Task 3	Task 4			
1999 (*16 – gr11)(*17 – gr12) (Age: 16 – 18 yrs.)	N	7.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	7.00	8.00	8.00	8.00
	Min	64.60	66.90	92.60	76.50	70.20	80.20	96.80	79.80	-8.20	-9.50	-12.10	-0.20
	Max	94.50	99.90	125.30	99.70	94.40	98.30	118.70	104.90	8.80	17.30	18.10	8.60
	Mean	<b>84.20</b>	<b>85.28</b>	<b>107.23</b>	<b>90.09</b>	<b>86.34</b>	<b>90.59</b>	<b>110.50</b>	<b>93.48</b>	<b>2.69</b>	<b>5.31</b>	<b>3.28</b>	<b>3.39</b>
	SD	10.06	11.72	10.51	8.24	7.79	6.31	6.50	9.32	5.43	9.93	10.48	3.34
	Median	84.70	85.75	107.35	93.00	88.10	90.85	110.70	95.65	4.20	8.25	1.90	2.05
	IQR	12.60	17.15	13.90	11.95	8.85	8.85	5.45	15.60	4.80	16.40	15.60	4.50
2000 (*16 – gr10)(*17 – gr11) (Age: 15 – 17 yrs.)	N	10.00	10.00	10.00	10.00	9.00	10.00	10.00	10.00	9.00	10.00	10.00	10.00
	Min	69.80	83.30	81.30	85.10	66.80	81.20	75.90	81.70	-23.50	-6.70	-26.60	-11.00
	Max	100.30	101.10	108.40	111.80	98.40	106.80	115.80	117.90	15.20	12.50	12.20	6.20
	Mean	<b>87.88</b>	<b>93.49</b>	<b>98.63</b>	<b>95.41</b>	<b>87.69</b>	<b>93.96</b>	<b>98.48</b>	<b>94.60</b>	<b>-0.36</b>	<b>0.47</b>	<b>-0.15</b>	<b>-0.81</b>
	SD	9.24	5.29	9.32	7.78	11.29	8.07	11.63	10.27	10.81	6.13	11.95	5.22
	Median	88.95	93.30	102.25	95.35	92.60	93.70	100.40	91.15	-1.30	-1.05	2.50	-1.75
	IQR	9.50	6.80	9.60	10.10	9.70	13.20	8.60	12.70	9.00	9.20	16.80	6.50
2001 (*16 – gr9)(*17 – gr10) (Age: 14 – 16 yrs.)	N	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00
	Min	62.60	70.80	91.20	73.60	61.80	77.20	81.30	75.70	-19.00	-19.50	-23.70	-13.80
	Max	96.40	108.70	117.20	107.70	99.60	100.70	118.70	104.00	23.90	11.50	19.60	16.10
	Mean	<b>82.62</b>	<b>89.91</b>	<b>100.18</b>	<b>91.74</b>	<b>84.24</b>	<b>89.90</b>	<b>103.25</b>	<b>92.97</b>	<b>1.62</b>	<b>-0.01</b>	<b>3.08</b>	<b>1.23</b>
	SD	9.23	8.21	6.61	8.89	7.68	6.47	8.91	8.07	9.33	6.98	10.49	8.04
	Median	94.30	89.15	98.80	90.80	85.50	91.60	104.00	93.95	0.40	0.85	5.45	2.90
	IQR	12.35	8.20	9.05	13.05	8.55	7.60	9.35	12.25	9.15	8.50	9.45	11.05
2002 (*16 – gr8)(*17 – gr9) (Age: 13 – 15 yrs.)	N	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
	Min	73.60	76.90	11.01	71.60	35.40	73.40	83.40	70.70	-61.10	-16.30	-24.40	-18.50
	Max	103.90	105.30	126.50	106.80	98.10	108.00	134.80	108.30	13.50	10.30	96.29	20.20
	Mean	<b>91.64</b>	<b>94.21</b>	<b>101.44</b>	<b>90.79</b>	<b>82.66</b>	<b>88.88</b>	<b>105.55</b>	<b>88.72</b>	<b>-8.98</b>	<b>-5.33</b>	<b>4.10</b>	<b>-2.07</b>
	SD	7.72	6.32	20.62	6.98	13.90	7.96	11.20	9.20	14.69	6.35	22.71	7.33
	Median	93.45	94.30	106.50	91.75	84.75	89.35	104.60	88.10	-6.55	-7.30	0.00	-2.35
	IQR	5.60	7.60	10.80	6.30	14.00	10.40	13.20	11.70	9.50	7.80	20.40	7.10

*N – number of participants; Min – minimum (smallest) value; Max – maximum (biggest) value; Mean – value average; SD – standard deviation; Median (p50) – the 50% separation point for the upper half from the lower half of all the participants; IQR – inter quartile range; Gr – Grade in school; yrs. – Age in years; '16 – 2016; '17 – 2017.*

Table 4.15 showed that the oldest age group (1999) showed an increase, an improvement, in all four tasks. While the 2000 age group and youngest age group

(2002) performed similar, with a decrease in three tasks. The 2001 age group showed an increase in two tasks and a decrease in the remaining two.

### **4.5.3 Objective two**

The second objective was to determine the significance of the difference between the 2016 and 2017 baseline values, including test-retest reliability for the Cogstate Sport test.

#### **4.5.3.1 Statistical analysis**

Objective two's results are shown in Table 4.15, Table 4.16, and Table 4.17. Three different statistical analysis were done; the T-test, the effect size (Cohen's D), and the interclass correlation coefficient (ICC).

The **T-test** was used to determine if there were any statistically significant differences between baseline values from 2011 to 2017 for all four tasks of the Cogstate sport test. The null hypothesis would be that there is no significant difference between the specified variables. The Bonferroni correction was used to adjust the p-value, if the significance value is less than 0.0125, the null hypothesis can be rejected.

The **effect size (Cohen's D)** was calculated for the difference between 2016 and 2017 Cogstate sport baseline test score. This score is used to indicate the standardized difference between two groups and helps to evaluate the differences found. The values can be interpreted from a clinical perspective as follow; 0.2 or less = Small; between 0.3 and 0.5 = Medium; between 0.6 and 0.8 = Large; and 0.9+ = Very large.<sup>[40]</sup> A positive value represents an improvement and a negative value represents a worsening on the baseline values from 2016 to 2017.

The **interclass correlation coefficient (ICC)** was used to determine the reliability of baseline values from two consecutive years. The values can be interpreted from a clinical perspective as follow; less than 0.40 = poor; between 0.40 and 0.59 = low; between 0.60 and 0.69 = marginal; 0.7 and 0.79 = adequate; between 0.8 and 0.89 = good; and 0.9 and more = excellent.<sup>[4]</sup>

#### **4.5.3.2 Tables and Figures**

Cogstate sport test statistical data are summarized in the following Tables:

- *Table 4.16 – T-test results for each task in the Cogstate sport test; Comparison between 2016 and 2017 baseline test values for the total participant group.*
- *Table 4.17 - Effect sizes based on the comparison between Cogstate sport baseline values on all four tasks for the year 2016 to 2017. The combined scores are for the total participant group.*
- *Table 4.18 - The interclass correlation coefficient between 2016 and 2017 baseline scores for the total participant group in the Cogstate sport test.*

### 4.5.3.3 Results

In Table 4.16 multiple testing of all four task were conducted simultaneously. The Bonferroni correction was used to adjust the p - value (0.0125). The results for the t-test show that there was a statistically significant difference for task one and two, but not for task three and task four.

*Table 4.16 – T-test results for each task in the Cogstate sport test; Comparison between 2016 and 2017 baseline test values for the total participant group.*

T-test	p-value	Significance of value	Null hypothesis
Task one - A detection task (psychomotor function)	<b>0.003*</b>	< 0.0125	Rejected, indicates a statistical significant difference.
Task two -An identification task (visual attention).	<b>0.005*</b>	< 0.0125	Rejected, indicates a statistical significant difference.
Task three - A one-Back task (visual learning).	<b>0.703</b>	> 0.0125	Can't be rejected, indicates no statistically significant difference.
Task four - A one card learning task (working memory).	<b>0.149</b>	> 0.0125	Can't be rejected, indicates no statistically significant difference.

*\*: significant different*

Table 4.16 shows that there is a statistically significant difference between 2016 and 2017 baseline values for task one and task two, but not for task three and four.

Table 4.17 shows the effect size (Cohen's D) of the difference between baseline values from 2016 to 2017, for all four tasks of the Cogstate sport test. This score is used to indicate the standardized difference between two groups and helps to evaluate the differences found. The values can be interpreted from a clinical perspective as follow; 0.2 or less = Small; between 0.3 and 0.5 = Medium; between 0.6 and 0.8 = Large; and 0.9+ = Very large.<sup>[40]</sup>

*Table 4.17 - Effect sizes based on the comparison between Cogstate sport baseline values on all four tasks for the year 2016 to 2017. The combined scores are for the total participant group.*

Task	Cohen's D	95% Confidence Interval	Interpretation
All four task combined	<b>-0.244</b>	-0.511 - 0.023	Small to medium effect
Task one - A detection task (psychomotor function)	<b>0.324</b>	0.059 - 0.590	Medium effect
Task two -An identification task (visual attention).	<b>0.270</b>	0.005 - 0.535	Small to medium effect
Task three - A one-back task (visual learning).	<b>-0.044</b>	-0.307 - 0.219	Small effect
Task four - A one card learning task (working memory).	<b>0.126</b>	-0.136 - 0.388	Small effect

Table 4.17 indicate a small to medium effect size for the differences found amongst all four tasks between 2016 and 2017 baseline values.



In Table 4.18 the ICC values were calculated to determine the test retest reliability between baseline values from 2016 to 2017 for each task of the Cogstate sport test. The values can be interpreted from a clinical perspective as follow; less than 0.40 = poor; between 0.40 and 0.59 = low; between 0.60 and 0.69 = marginal; 0.7 and 0.79 = adequate; between 0.8 and 0.89 = good; and 0.9 and more = excellent.

*Table 4.18 - The interclass correlation coefficient between 2016 and 2017 baseline scores for the total participant group in the Cogstate sport test.*

Tasks	ICC	95% Confidence Interval	Interpretation
All four task combined	<b>0.53</b>	0.376 - 0.652	Low
Task one - A detection task (psychomotor function)	<b>0.31</b>	0.138 - 0.471	Poor
Task two -An identification task (visual attention).	<b>0.5</b>	0.339 - 0.627	Low
Task three - A one-Back task (visual learning).	<b>0.17</b>	-0.018 - 0.342	Poor
Task four - A one card learning task (working memory).	<b>0.58</b>	0.439 - 0.687	Low

Table 4.18 showed that the ICC values for all combined task, task two and task four were found to be low, while task one and three were found to be poor.

### **4.5.4 Objective three**

The third objective was to determine if differences in baseline values with respect to sex and age observed in objective one were statistically significant for the Cogstate sport test.

#### **4.5.4.1 Statistical analyses**

Objective three's results are in Table 4.18., and Table 4.19. Two different statistical analysis were done; The Kruskal-Wallis non-parametric test, and the two-way ANOVA. All the results shown for objective three are derived from the combined score of all four Cogstate Sport tasks.

The Kruskal-Wallis non-parametric test was used as an alternative to the T-test because of small sample sizes within combinations of sex and year of birth.

The two-way ANOVA was used to test between two variables; either between the different age groups, the two sexes or between age and sex.

The null hypothesis would be that there is no significant difference between the specified variables. If the significance value is less than 0.05, the null hypothesis can be rejected.

#### **4.5.4.2 Tables and Figures**

The Cogstate sport descriptive data are summarized in the following Tables:

- *Table 4.19 - Kruskal-Wallis non-parametric test results; Comparison between 2016 and 2017 Cogstate sport baseline test values for the different age groups of both sexes.*
- *Table 4.20 – Two-way ANOVA test results for the combined Cogstate sport baseline values between 2016 and 2017.*

### 4.5.4.3 Results

In Table 4.19 the Kruskal-Wallis non-parametric test was used to determine if there were any statistically significant differences between baseline values from 2016 to 2017 for the Cogstate sport test for the different age groups. All the results are derived from the combined score of all four Cogstate Sport tasks.

*Table 4.19 - Kruskal-Wallis non-parametric test results; Comparison between 2016 and 2017 Cogstate sport baseline test values for the different age groups of both sexes.*

Age group	p - value	Significance of value	Null hypothesis
1999 ( '16 – gr11)( '17 – gr12) (Age: 16 – 18 yrs.)	<b>0.0641</b>	> 0.05	Can't be rejected, indicates no statistically significant difference.
2000 ( '16 – gr10)( '17 – gr11) (Age: 15 – 17 yrs.)	<b>0.2053</b>	> 0.05	Can't be rejected, indicates no statistically significant difference.
2001 ( '16 – gr9)( '17 – gr10) (Age: 14 – 16 yrs.)	<b>0.2482</b>	> 0.05	Can't be rejected, indicates no statistically significant difference.
2002 ( '16 – gr8)( '17 – gr9) (Age: 13 – 15 yrs.)	<b>0.3263</b>	> 0.05	Can't be rejected, indicates no statistically significant difference.

*Gr – Grade in school; yrs. – Age in years; '16 – 2016; '17 – 2017.*

Table 4.19 showed that there was no statistically significant difference found between 2016 and 2017 baseline values for participants within the same age groups, regardless of sex.

In Table 4.20 two-way ANOVA results are shown for the difference between 2016 and 2017 Cogstate sport baseline values for male- and female participants, as well as the different age groups. All the results are derived from the combined score of all four Cogstate Sport tasks.

Table 4.20 – Two-way ANOVA test results for the combined Cogstate sport baseline values between 2016 and 2017.

Variables	p - value	Significance value	Null hypothesis
Difference between <b>age groups within the females</b> participant group	<b>0.0034*</b>	< 0.05	Rejected, indicates a statistical significant difference.
Difference between <b>age groups within the males</b> participant group	<b>0.0068*</b>	< 0.05	Rejected, indicates a statistical significant difference.
Difference <b>between male and female</b> participant groups	<b>0.26</b>	> 0.05	Can't be rejected, indicates no statistically significant difference.
Difference between <b>age groups of the total participant group</b>	<b>0.0001*</b>	< 0.05	Rejected, indicates a statistical significant difference.
The interaction between sex and age	<b>0.25</b>	> 0.05	Can't be rejected, indicates no statistically significant interaction

\*: *significant different*

Table 4.20 shows that there is a statistically significant difference between age groups within the same sex, but not between sexes. There was also no significant interaction between age and sex.

## 4.2.5 The summary of all the results for the Cogstate sport test.

In Table 4.21 the summarized trends and interpretation thereof are shown for each objective for the Cogstate sport test.

*Table 4.21 – A summary of all the Cogstate sport test results for each objective.*

Objective one - to determine and quantify changes in baseline values for the Cogstate sport test for all the involved participants measured at the start of the 2016 and 2017 sports season.				
Variable	Trend	Table	Direction	Interpretation
<i>Males, females and the total group.</i>	Yes	4.12	10/12 decreased	All performed worst
<i>All the different age groups.</i>	Unclear	4.13	7/16 decreased	The two youngest age groups performed worst.
<i>Different age groups in the female participant group.</i>	Unclear	4.14	11/16 decreased	The two youngest age groups performed worst.
<i>Different age groups in the male participant group.</i>	Unclear	4.15	7/16 decreased	The two youngest age groups performed worst.
Objective two - to determine the significance of the difference between the 2016 and 2017 baseline values, including test-retest reliability in the Cogstate sport test.				
<i>T-test results for each task in the Cogstate sport test for the total participant group.</i>	Task one ( $p = 0.003$ ) Task two ( $p = 0.005$ ) Task three ( $p = 0.703$ ) Task four ( $p = 0.149$ )	4.16		Task one and two showed a statistically significant difference, task three and four did not.
<i>Effect sizes, Cohen's D (D) values for the total group and all four tasks.</i>	Combined (D: 0.244) Task one (D: 0.324) Task two (D: 0.270) Task three (D: -0.044) Task four (D: 0.126)	4.17		Small to medium effect sizes
<i>The ICC value for the total participant group and all four tasks</i>	Combined (0.53) Task one (0.31) Task two (0.5) Task three (0.17) Task four (0.58)	4.18		Poor to low test re-test reliability
Objective three - to determine if differences in baseline values with respect to sex and age observed in objective one were statistically significant for the Cogstate sport test.				
<i>Kruskal-Wallis non-parametric test results for the different age groups.</i>	Born 1999 ( $p = 0.064$ ) Born in 2000 ( $p = 0.205$ ) Born in 2001 ( $p = 0.248$ ) Born in 2002 ( $p = 0.326$ )	4.19		No statistically significant difference found for any of the age groups
<i>Two-way ANOVA test results for the combined Cogstate sport baseline values between 2016 and 2017.</i>	Within male group: ( $p = 0.0068$ ) Within female group: ( $p = 0.003$ ) Between sexes: ( $p = 0.262$ ) Between age groups: ( $p = 0.245$ )	4.20		No statistically significant difference between sexes or an interaction between sex and age. Age does show a statistically significant difference between age groups with in a sex.

# Chapter 5 – Discussion

## 5.1 Introduction

This chapter will discuss the results of the statistical analysis shown in Chapter four. The results will be discussed in relation to the current literature to determine if it is consistent with previous research or gives way for a new research question.

## 5.2 Chapter flow

The discussion will follow a similar order as used in Chapter four, discussing the KD test and Cogstate test separately and per objective.

Chapter five will continue to formulate the conclusion and address the limitations of this study and the recommendations for further research.

## 5.3 Discussion

It is suggested that the use of baseline values are one of the best methods for unbiased diagnosis and accurate return to play decision making.<sup>[3]</sup> The present literature favoring the implementation of baseline testing encourages the use of pre-season baseline testing prior to any practice or competition.<sup>[4,9,12,13]</sup> Should the athlete sustain a concussive injury, his or her after-injury values can be compared to their own baseline values.<sup>[3,16,17]</sup>

The main aim of this study was to investigate and report the difference in concussion baseline values from one sport season to the next, and to investigate the test-retest reliability of baseline values after one year.

This study included the baseline values of a neuropsychological test and an oculomotor test often used in the assessment of concussion severity and the return to play decision making. The tests consisted of the King-Devick test and the computer-based Cogstate sport test. Test-retest coefficients investigated included; psychomotor function, visual attention, working memory, visual learning ability and lastly the combined time (in seconds) score for the KD test.

### 5.3.1 Demographical summary of participants

This study was conducted at a large Pretoria-based high school (Hoërskool Waterkloof). The data was captured during the 2016 and 2017 pre-sporting season (February and March) by the researcher, Ms. J. Coetzer, as part of her duties running an existing concussion clinic at the school.

Baseline data were collected from 108 participants for the King-Devick test (Table 4.1) and 112 participants for the Cogstate Sport test (Table 4.11). All participants were high school athletes between the ages of 13 and 18, born in the years 1999 to 2002. Both male and female participants were included in the current study.

Approximately 30% of all incidences of concussion reported in individuals, between the ages of five (5) and 19 years of age, are sport related.<sup>[4,5,6]</sup> The sporting codes the adolescents partook in were neither limited nor pre-determined. The consensus was that those that played in contact sports such as rugby and high velocity hitting sports like hockey and cricket were more at risk to sustain a concussive injury.<sup>[2,3,25]</sup> Thus, all athletes participating in these high-risk sports were encouraged by the school to enroll in the program.

For the KD test 55.55% of all participants were male and 44.44% female (Table 4.1), while a similar trend was seen for the Cogstate sport test where 60.71% and of total participants were male and 39.28% female (Table 4.11). This showed that male adolescents showed a higher percentage of adhering to the concussion program.

A study done by Trost et al. (2001) investigated the age and gender differences in physical activity in a youth sport.<sup>[41]</sup> The authors found that males were consistently more active and willing to partake in vigorous and high-risk activity, such as rugby, than females.<sup>[13,41]</sup> This could pose a plausible explanation for the larger number of male participants in this study.

The difference in program adherence amongst age groups was interesting to note. The adherence to baseline testing declined with an increase in age. The younger age groups (those born in 2002 and 2001) were significantly more in numbers than the older groups (those born in 2000 and 1999). The trend for sport participation to decrease with age had been noted in the literature as well, in the same study done by

Trost et al. (2001) it was reported that participation declined with age,<sup>[41]</sup> specifically in late adolescence into early adulthood.<sup>[42]</sup>

The two youngest age groups represented 70.37% (Figure 4.1) and 71.42% (Figure 4.5) of the total number of participants for the KD test and Cogstate sport test, respectively. Program adherence according to age groups might be due to the parents who had a bigger influence on the day to day schedule of the younger age groups (2002 and 2001) than what they did in the older age groups (2000 and 1999).<sup>[43]</sup>

Important to note would be how to define the year of birth as it is referred to in this study. The age groups were defined by year of birth for easy standardization. At the time of this study (2016 and 2017) the age groups were as follow:

- In 2016 those born in **2002** were in the 8<sup>th</sup> grade and considered to be between 13 and 14 years of age. In 2017 those born in 2002 were in the 9<sup>th</sup> grade and considered to be between the ages of 14 and 15.
- In 2016 those born in **2001** were in the 9<sup>th</sup> grade and considered to be between 14 and 15 years of age. In 2017 those born in 2001 were in the 10<sup>th</sup> grade and considered to be between the ages of 15 and 16.
- In 2016 those born in **2000** were in the 10<sup>th</sup> grade and considered to be between 15 and 16 years of age. In 2017 those born in 2000 were in the 11<sup>th</sup> grade and considered to be between the ages of 16 and 17.
- In 2016 those born in **1999** were in the 11<sup>th</sup> grade and considered to be between 16 and 17 years of age. In 2017 those born in 1999 were in the 12<sup>th</sup> grade and considered to be between the ages of 17 and 18.

#### **Summary of demographic findings from Table 4.1 and Table 4.10:**

- There were more males enrolled in the concussion program than females, for both tests in total.
- The difference seen in participation amongst sexes might be due to males being more willing to partake in high-risk sports than females.
- Program adherence decreases with age. The two younger age groups were significantly more than the two older age groups; this was especially true for males.
- The difference seen in participation amongst various age groups might be due to more parental involvement in the younger age groups.



### 5.3.2 The King-Devick test

This section will discuss the KD test results found in this study and how it pertains to the current literature. The interpretation of the KD test results will be discussed per objective.

The KD test is a visual performance measure and proven to be effective in diagnosing signs and symptoms associated with concussion in the acute phase.<sup>[30,31,33]</sup> The KD test is capable of assessing specific neurological function, which in turn is more evidence-based than subjective symptom checklists.<sup>[29]</sup> The KD test is able to evaluate saccadic eye movement, attention, coordination, and language; all areas known to be affected by a concussive injury.<sup>[6,15,19,29,31,33]</sup>

The baseline scores are simple to record; the time taken to read each of the three cards out loud is recorded. All three times (in seconds) are combined, and then the fastest time without errors is used as the baseline.<sup>[15,19,29,32,37]</sup>

#### 5.3.2.1 Discussion for objective one

The first objective was to determine and quantify changes in baseline values for the KD test for all the involved participants measured at the start of the 2016 and 2017 sports season.

The descriptive statistics mean, median, standard deviation and inter-quartile range were used to describe the test scores from the King-Devick (KD) test. The KD test baseline value is a score of the total time it took to complete the test, and it is measured in seconds. This means that a decrease in the total score, indicates a faster time and that is seen as an improvement in baseline values.<sup>[2,18,19,29]</sup>

The KD test largely relies on baseline values, as normative data for adolescents are not established.<sup>[32,33]</sup> Research reports that a three-second deviation from the baseline value is still acceptable, but that five seconds (slower) is an indication of a concussion.<sup>[2,18,19,29]</sup>

The descriptive results for sex and the total group, regardless of age, are shown in Table 4.2. The mean difference for the total group showed an improvement of 5.04% (3.02s) in baseline values from 2016 (49.13s) to 2017 (46.11s). This enforces the importance of baseline testing at the start of the sporting season, especially since the

observed improvement in baseline values, after just one year, reached the acceptable amount of suggested standard deviation of three seconds.

In Table 4.2 the same improvement was observed in baseline values from 2016 to 2017 for both sexes. The female participants showed a 3.68% (2.21s) improvement, and the male participants showed an even bigger improvement of 6.12% (3.67s) after just one year. Current literature supports this notion by suggesting individual baseline testing should be conducted since males and females cannot be accurately assessed on the same norms, should there be any available.<sup>[36]</sup>

Improvement in cognitive function had been noted to occur between the ninth to eleven grades.<sup>[18,36]</sup> In Table 4.3 results for the difference in mean baseline values from 2016 to 2017 are shown for the various age groups. An improvement ranging from 7.7% (4.72s) to 1.41% (1.85s) was observed for all age groups. The oldest age group, those born in 1999 (age 16 to 18) showed the least improvement, while the youngest age group, those born in 2002 (age 13 to 15) showed the biggest improvement after one year. These results emphasize the need to consider the maturation stage in the management of concussion, as the rate of change seems more pronounced in younger participants.<sup>[20,36]</sup>

Literature reports that test scores improve with age, due to the improvement of the developing brain and the stabilizing of eye saccades that are associated with maturation.<sup>[17,36]</sup> Baseline testing is suggested to be administered regularly to accommodate these changes.<sup>[17,36]</sup> These findings in the current study are consistent with the current literature when considering the improvement in mean baseline values across all the participants for the KD test from 2016 to 2017.

There was a difference between the mean baseline values from 2016 to 2017 between sexes. For males participants (Table 4.5) differences ranged from 8.89% to 2.29%, and for females participants (Table 4.4) differences ranged from 4.97% to 0.73%. Males and females had been found to perform differently on neuropsychological tests, especially in perceptual-motor speed and visuospatial tasks, which could be a plausible reason for the difference seen in mean baseline values between the two sexes.<sup>[15]</sup>

A learning effect could offer an explanation for the overall difference observed in mean baseline values from 2016 to 2017. In literature signs of a learning effect between the

first and second test trial, in certain studies, had been noted.<sup>[2,31]</sup> However, the study done by Seidman et al. (2015) found that these learning effects were not statistically significant ( $p = 0.73$ ).<sup>[30]</sup>

In conclusion, the results for objective one show an improvement for both sexes and each of the age groups in baseline values after one year. There was also a difference observed between the changes of baseline values from one year to the next between sexes. In Figure 4.1 it is visually depicted that there is a decrease seen in baseline values. This means less time was taken to complete the KD test baseline in 2017 (46.11s) than what it did in 2016 (49.13s). This 3.02s improvement firmly warrants a new baseline as it would alter the three-second deviation mark suggested by research, making it possible for misdiagnoses when using the five-second deviation as a reference.<sup>[2,18,19,31]</sup> Although, the improvement observed in baseline values are consistent with previous research, the implication of this improvement, and the fact that it may have the potential to surpass the suggested norm for standard deviation had yet to be addressed in research. The younger age groups showed a more pronounced improvement, this highlights the need for concussion management programs to closely monitor the time elapsed between testing sessions for these young age categories.

### **Summary and implementation of findings for objective one:**

- The mean differences between baseline values from 2016 to 2017 showed a decrease, indicating an improvement in baseline values. This means the time taken to complete the 2017 KD baseline test was less than the time it took on the 2016 baseline test.
- Both sexes showed an improvement in their baseline values from 2016 to 2017.
- All the age groups showed an improvement in their baseline values from 2016 to 2017.
- The biggest difference in baseline values was noted amongst the two youngest age groups (2002 and 2001).
- Improvement in baseline times can be attributed to the natural structural changes, and improved cognitive function and saccadic eye movement that is seen with age.

- The implication of this improvement on the suggested norm for standard deviation from baseline values had yet to be addressed in research.
- Changes found after a 1 year period in these age groups is an indication of the importance of baseline testing at the start of the sporting season.

### **5.3.2.2 Discussion for objective two**

The second objective was to determine the significance of the difference between the 2016 and 2017 baseline values, including test-retest reliability in both the KD test. Three main statistical tests; Kruskal-Wallis non-parametric test, effect size (Cohen's D) and the interclass correlation coefficient (ICC) values were used to analyze the KD test data for objective two. No significant difference ( $p < 0.05$ ) between KD test baseline values from 2016 to 2017 would support the null hypothesis.

In Table 4.6 a statistically significant difference was found ( $p = 0.004$ ) between the baseline values of 2016 to 2017. This statistically significant difference supports the current research that suggests the baseline test scores improve with age, due to the structural changes, improved cognitive functioning of the developing brain, and stabilization of saccadic eye movements.<sup>[17,20]</sup>

A study done by Galetta et al. (2015) found similar results in their adolescent participant sample. They concluded that KD scores improve with age, and that regular baseline testing is essential to aid in accurate after-injury test interpretation.<sup>[36]</sup>

The effect size (Cohen's D) was calculated to evaluate the statistical differences found between 2016 and 2017. The Cohen's D: 0.38 indicated a small to medium effect size for the difference between 2016 and 2017 baseline values. This means that the difference noted in objective one is a small to a medium statistically significant difference. In a school concussion management setup, this small to medium difference can influence greatly the concussed patient's diagnosis, management, and return to play decisions. The potential for Second-impact syndrome amongst adolescent athletes are higher than for adults,<sup>[4,6,8,13,21,25,27]</sup> thus no difference, although small, can be overlooked during the proper and safe management of an adolescent athlete.

The reliability of KD baselines values from one year to another was determined by the interclass correlation coefficient (ICC) and the result of 0.54 indicated a fairly low

correlation between 2016 and 2017 baseline data for this study. The minimum clinically acceptable ICC value is 0.6.<sup>[5,18]</sup> The value found in this study means that the test-retest reliability from one year to the next is not clinically acceptable.

A study was done by Vartianen et al. (2014), investigating test-retest reliability for the KD test in the pursuit of establishing norms, found an ICC value of 0.92 indicating a good test-retest reliability between two consecutive trials done on the same day.<sup>[2]</sup> Their average participant age was 23.8 years and they were all male ice hockey players.<sup>[2]</sup>

The current study completed two trials one year apart, in two separate sessions. The most plausible explanation for the difference in reliability might be due to the amount of time that passed between the two sessions in the current study.<sup>[44]</sup> It could be argued that time between sessions sees a decline in test-retest reliability and this could be justified by the natural growth and development seen in the immature brain over time.<sup>[17,20,36,44]</sup>

In conclusion, the difference between 2016 and 2017 baseline values is statistically significant with a small to medium effect size. The test-retest reliability seems to be negatively affected by time, rendering the test-retest reliability below clinically acceptable values after a single year. These results warrant a new pre-season baseline at the beginning of each new sporting season, suggesting that concussion periodization should be considered in the management.

A concussive injury normally occurs during the in-season or competition phase of a sport season, this is usually three to four months after the pre-season in the high school setting. If proper baseline testing is conducted during each new pre-season the time elapsed for the potential after-injury test is much less than if you would have used the previous season's baseline. The proper timing and planning based on the available time to increase test re-test reliability is what can be referred to as periodization in concussion management. The year-old KD baseline test would not suffice for the proper clinical management of a concussive injury as the test re-test reliability is too low because of the amount of time passed between testing sessions.

### **Summary and implication of findings for objective two:**

- There is a statistically significant difference between 2016 and 2017 baseline values with a low to medium effect size.
- Test-retest reliability was found to be low between 2016 and 2017 baseline values, and unfit for clinical standards.
- It is postulated that test-retest reliability decreases the more time elapses between sessions.
- Annual baseline testing, at the beginning of each sporting season, may improve test-retest reliability scores between baseline testing values and after-injury testing values, and aid in proper injury management.
- The implication is that periodization should be considered in the concussion management program, to control for the time elapsed between sport seasons and baseline and after-injury testing sessions.

### 5.3.2.3 Discussion of objective three

The third objective was to determine if differences in baseline values with respect to sex and age observed in objective one were statistically significant for the KD test. No significant difference ( $p < 0.05$ ) between KD test baseline values from the two sexes or between KD baselines from the various age groups would support the null hypothesis.

The Kruskal-Wallis non-parametric test was used as an alternative to the T-tests and ANOVA test because of the small sample sizes within combinations of sex and year of birth and to control for the outlier.

Results for the Kruskal-Wallis test are shown in Table 4.9. No statistically significant differences between KD baseline values from 2016 to 2017 were observed amongst male participants ( $p = 0.29$ ) or amongst female participants ( $p = 0.737$ ). This means that the statistically significant difference seen in the total participant group ( $p = 0.004$ ) was between sexes and not between participants of the same sex. Current literature supports this finding by suggesting individual baseline testing should be conducted since males and females may not be accurately assessed on the same norms.<sup>[26,36]</sup>

The results for the various age groups in Table 4.9 are as follow; for those born in 1999 (age 16 to 18) ( $p = 0.633$ ), those born in 2000 (age 15 to 17) ( $p = 0.750$ ) and those born in 2001 (age 14 to 16) ( $p = 0.169$ ). Thus, there was no statistically significant difference for KD baseline values from one year to the next for participants born in those three years. However, a statistically significant difference ( $p = 0.044$ ) was found between baseline values after one year for those born in 2002 (age 13 to 15).

There were indeed differences in mean values observed for all participants (Table 4.2), for both sexes (Table 4.4 and Table 4.5) and all age groups (Table 4.3). These results from the Kruskal-Wallis test suggest that participant's sex and a younger age might be the biggest contributing factors in the difference found in baseline values for the current study. These results can be explained by the fact that the differences between sexes in cognitive performance and development are more prominent in the younger spectrum of adolescence.<sup>[17,20,36]</sup>

### **Summary and implications of findings for objective three:**

- There is no statistically significant difference between consecutive KD baselines within the male participant group.
- There is no statistically significant difference between consecutive KD baselines within the female participant group.
- Thus, the difference seen between consecutive KD baselines in the total group may be due to the difference between sexes and not between participants of the same sex.
- There is no statistically significant difference between consecutive KD baselines in age groups born in 1999, 2000 or 2001.
- There is a statistically significant difference between consecutive KD baselines within the participant group born in 2002.
- Results from this study suggest that two main factors in the difference between on 2016 and 2017 baseline values might be attributed to the sex of a participant and the younger age of the participant.
- The implications of these findings are that both sexes warrant their own baselines, and that concussion management should take care to ensure the renewal of baseline for each new sporting season, especially for the younger age groups.



### 5.3.3 The Cogstate Sport test

This section will discuss the results found in this study for the Cogstate sport test and how it pertains to the current literature with regards to neuropsychological testing. The interpretation of the Cogstate sport test results will be discussed per objective.

Neuropsychological testing is very popular around the world and is described as the cornerstone of concussion management.<sup>[3,5,6,12,23]</sup> The Cogstate program is a brief neuropsychological test battery specifically designed to measure cognitive function over repetitive short intervals and to track any cognitive changes during these time intervals. Due to the fact that the test is computerized the administration and scoring are automated and thus standardized.<sup>[5]</sup> The test can be administered repeatedly without significant practice effects due to the randomization of stimuli.<sup>[29]</sup>

The test battery consists of four tasks, which takes approximately eight (8) to 15 min to complete.<sup>[3,6]</sup> These tasks include simple stimuli requiring decisive responses within the set rules of each task (explained in detail in section 2.2.8.1.1).<sup>[5,28]</sup> Task are presented as a card game, with a universal deck of playing cards as the stimulus set.<sup>[5,31]</sup> Each task needs either a “yes” or a “no” answer, the “K” key on the keyboard represents “yes” while the “D” key represents “no”.<sup>[28]</sup> All results are measured in milliseconds to indicate response speed and by the number of errors to assess accuracy.<sup>[28]</sup>

The Cogstate battery can be quantified into a single score by means of the standard data extract. The four task’s composite scores need to be computed into the extract. This method of combining the scores was used in the data analysis of this study and had been provided by the Science director (Adrian Schembri) of the research division at Cogstate in Melbourne, Australia via e-mail correspondence (Appendix L).

**The units of measurement for the four tasks are as follow:**<sup>[28]</sup>

- Task one: A detection task (psychomotor function)
  - Reaction time was measured in milliseconds (speed), which was then normalized using a logarithmic base transformation (Log10 ).

- Task two: An identification task (visual attention)
  - Reaction time was measured in milliseconds (speed), which was then normalized using a logarithmic base transformation (Log10).
- Task three: A one card learning task (visual learning).
  - The proportion of correct answers was the performance measure thus accuracy was evaluated. This was normalized using an arcsine square root transformation.
- Task four: A one-back task (working memory).
  - The proportion of correct answers was the performance measure thus accuracy was evaluated. This was normalized using an arcsine square root transformation.

### 5.3.3.1 Discussion of objective one

The first objective was to determine and quantify changes in baseline values for the Cogstate sport test for all the involved participants measured at the start of the 2016 and 2017 sports season.

The descriptive statistics mean, median, standard deviation and inter-quartile range were used to describe the test scores from the Cogstate sport test. For the Cogstate test, a low numerical value is considered poor while a higher numerical value is considered good. Thus an improvement would be seen as an increase in total numerical value and a worsening or decline in value would be seen in the decrease in total numerical value.

#### 5.3.3.1.1 Discussion of the results for the total group, male and female participant groups.

The descriptive results for sex and the total group, regardless of age, are shown in Table 4.12. The mean difference for each task of **the total group** showed a decline ranging from 3.43 to 1.14 in all but task three's baseline values from one year to the next. Task three (visual learning) showed an improvement of 1.3 in mean score value. This indicates that all participants performed worse during their baseline testing in the consecutive year than in the first year.

A similar trend was seen amongst the **male** participants. A decrease in mean score was observed for task one, task two and task four ranging from 2.71 to 0.08. Task three, however, showed an increase in mean score of 3.02. This indicates that all male participants, regardless of age, performed worse on their baseline in the consecutive year than in the first year.

The **female group** presented a slightly different trend and, their performance were worse than the male group. They showed a decrease in mean scores on all four task ranging from 4.53 to 1.36. This indicates that all female participants, regardless of age, performed slightly worse on their baseline in the consecutive year than in the first year.

It had previously been found that males and females perform differently on neuropsychological tests, especially in perceptual-motor speed and visuospatial tasks.<sup>[15]</sup> However, the mean values and differences observed in the current study, between the sexes, showed similar trends and values with the exception of task three which was the visual learning task.

#### **5.3.3.1.2 Discussion of the results for the various age groups.**

In Table 4.13 the results for each task are shown by age. The oldest age group, those born in **1999 (age 16 – 18)** showed an improvement in mean scores for task two, task three and task four ranging from 4.7 to 0.92. Task one (psychomotor task), however, showed a decrease in mean score value of 0.75. This contrasts the findings of the total group, who showed an improvement in task three (visual learning) baseline values from 2016 to 2017, instead of in task one.

The second oldest age group, those born in **2000 (age 15 – 17)** showed an improvement in mean scores for task one, task two and task three ranging from 2.33 to 0.9. Task four (working memory task), however, showed a decrease in mean score value of 0.86. This contrasts the findings of the total group, who showed an improvement in task three (visual learning) baseline values from 2016 to 2017, instead of in task four.

The second youngest age group, those born in **2001 (age 14 – 16)** showed an improvement in mean scores for task two and task four ranging from 0.48 to 0.2. Task

one (visual learning) and task four (working memory task), however, showed a decrease in mean score value ranging from 0.8 to 0.09. This contrasts the findings of the total group, who showed an improvement in task three (visual learning) baseline values from 2016 to 2017, instead of in task one and task four.

The youngest age group, those born in **2002 (age 13 – 15)** showed an improvement in mean scores of 1.17 only for task three. Task one, task two and task four, however, showed a decrease in mean score value ranging from 7.34 to 2.86. This shows a similar pattern as seen in the total group. The fact that this was the largest age group with the biggest observed difference in mean score values might play the biggest role in the data seen for the total group.

The trend seen in the improvement of baseline values, or rather increase instead of a decrease in values, with age had been noted in the literature and is attributed to structural changes and development of the immature brain.<sup>[17,18,36]</sup> Cognitive performance had also been noted to be subject to many confounding factors, such as hormonal changes and social pressure, that accompany adolescences.<sup>[18]</sup> All these confounding factors may negatively affect cognitive performance and lead to variations in results.<sup>[18]</sup>

Interesting to note in the current study was the difference in task performance between age groups. Each task test a different cognitive domain, it might be worth considering the 'neurological pruning', a period of dynamic structural changes within the neurological structure and cognitive functioning of the brain, that had been suggested during the adolescent period.<sup>[20]</sup>

The oldest age group those born in **1999 (age 16 – 18)** performed worse in task one, the psychomotor task. The second oldest age group, those born in **2000 (age 15 – 17)** performed worse in task four, the working memory task. The second youngest age group, those born in **2001 (age 14 – 16)** performed worse in task one, the visual learning task, and task four, the working memory task. While the youngest age group, those born in **2002 (age 13 – 15)** only performed well in task three, the visual learning task. Further research into the noted trend is suggested. More insight might aid in the diagnosis of a concussion and the management thereof if it is known which cognitive domain at a certain age might be more affected by a concussive injury. The

implication of this had yet to be addressed in the currently available research on adolescent athletes.

### **Summary and implications of findings for objective one:**

- The mean difference for each task of **the total group** showed a decline ranging from 3.43 to 1.14 in all but task three's baseline values from one year to the next.
- Task three (visual learning) showed an improvement of 1.3 in mean score value for the total group.
- Males and females showed similar trends in performance to the total group, with the exception of task three in the female participant group that also showed a decrease.
- Interesting to note in the current study was the difference in task performance between age groups. Each age group performed differently in the four cognitive domains, this observation might be novice to the research community, as it was not noted in the current literature.
- More insight might aid in the diagnosis of a concussion and the management thereof if it is known which cognitive domain at a certain age might be more affected by a concussive injury.
- The implication of this had yet to be addressed in the currently available research on adolescent athletes.

### 5.3.3.2 Discussion of objective two

The second objective was to determine the significance of the difference between the 2016 and 2017 baseline values, including test-retest reliability in the Cogstate Sport tests. Three main statistical tests; the T-test, the interclass correlation coefficient (ICC) values and effect size (Cohen's D) were used to analyze the Cogstate sport test data for objective two.

The results for the t-test are shown in Table 4.16. To test if there was a difference between baseline values between all four tasks, the Bonferroni correction was used. This implies the significance value be divided by the number of tests conducted simultaneously. Thus the significance of the p-value was adjusted to 0.0125 for this test.

No significant difference ( $p \leq 0.0125$ ) between the 2016 and 2017 baseline values for the total group would support the null hypothesis. The results showed a statistically significant difference for task one ( $p = 0.003$ ) and task two ( $p = 0.005$ ). However, no statistically significant difference was reported for task three ( $p = 0.703$ ) and task four ( $p = 0.149$ ).

The effect size (Cohen's D) for each task are shown in Table 4.17 the results range from 0.324 to -0.044 indicating a small effect size for all four tasks of the Cogstate sport test.

The interclass correlation coefficient (ICC) was used to determine the test-retest reliability of baseline values from 2016 to 2017. The ICC values are shown in Table 4.18 the results range from 0.58 to 0.17 indicating low test-retest reliability for all four tasks.

A study was done by MacDonald (2015) on high school athletes tested the reliability of a computerized neurocognitive baseline test from one year to the next.<sup>[5]</sup> Macdonald (2015) reported similar marginal to low ICC values ranging from 0.4 to 0.67 in their study.<sup>[5]</sup>

Research suggested that an ICC value of 0.6 is the minimum to be an acceptable value for test-retest reliability, within a clinical setting.<sup>[5,18]</sup> The low to poor test-retest reliability shown between 2016 baseline values and 2017 baseline values for the current study are below clinical standards, suggesting that 12 months between one

testing (baseline test) session and the next (after-injury test) will not be the best approach for diagnosis in the management of concussion.

The low test-retest reliability in the current study could be attributed to the time elapsed between testing sessions. A study done by Bruce et al. (2016) investigated the concern regarding the recent literature reporting poor test-retest reliability for computerized neuropsychological testing. Bruce et al. (2016) found that test-retest reliability seemed to decline with time.<sup>[44]</sup> However, Bruce et al. (2016) suggested that regular baseline testing may have the potential to improve the test-retest reliability.<sup>[44]</sup>

This would suggest that proper concussion management warrants annual baseline testing in the pre-season, before any form of contact play. Conducting annual baselines during the pre-season will ensure that the time between the baseline testing session and the potential after-injury testing session is much less than 12 months, and this could improve test re-test reliability. A year between baseline values and potential after-injury tests would not suffice, with annual baseline testing the time between actual baseline testing and the end of the sport season would be between three to seven months.

A plausible reason for the observed variability in test-retest reliability scores, observed with elapsed time, could be the significant structural changes seen in the adolescent brain, representing the natural growth and development that takes place during adolescence.<sup>[17,20]</sup>

On a practical level, this would suggest that timing and planning plays an important role in the holistic approach to effective concussion management. The importance of periodization in the management of concussion had yet to be properly addressed in the currently literature as it pertains to adolescents. Schools should consider planning their baseline testing during their pre-season as close to their in-season (competing season) as possible to help ensure better test-retest reliability between baseline values and after-injury values to aid in a more accurate diagnosis. Although various schools and sporting codes vary in their pre-season and in-season duration and time of year, it still proves to be a variable within the school's control.

### **Summary and implications of findings for objective two:**

- A statistically significant difference was observed for task one (psychomotor task) and task two (visual attention task)
- No statistically significant difference was seen for task three (visual learning) and task four (working memory).
- However, all effect sizes were low to poor, indicating that the magnitude of the differences observed in objective one was small.
- Low test-retest reliability was found for each task between 2016 and 2017 baseline values. This may be due to the time elapsed between testing sessions, and shorter periods between testing could increase test-retest reliability.
- On a practical level, the low test-retest reliability would suggest that shorter time periods (less than 12 months) between testing sessions could be the solution to effective concussion management.
- Although various schools and sporting codes vary in their pre-season and in-season duration and time of year, it still proves to be a variable within the school's control.
- The importance of periodization in the management of concussion management had yet to be properly addressed in the currently available literature pertaining to adolescents and needs to be considered in future research.

### **5.3.3.3 Discussion of objective three**

The third objective was to determine if differences in baseline values with respect to sex and age observed in objective one were statistically significant for the Cogstate sport test. No significant difference ( $p < 0.05$ ) between the two sexes or between the various age groups would support the null hypothesis.

Due to an outlier in the data the non-parametric Kruskal-Wallis test was used to determine statistically significant differences in baseline values within the different age groups. The two-way ANOVA was used to determine statistically significant differences in baseline values with respect to sex and age.



The results of the Kruskal-Wallis test are shown in Table 4.19. The results showed p-values ranging from 0.326 to 0.064 indicating that there were no statistically significant differences between 2016 to 2017 baseline values amongst participants of the same age groups. However, in Table 4.20 the two-way ANOVA test showed a statistically significant difference ( $p = 0.0001$ ) between 2016 and 2017 baseline values between the different age groups. This suggests that athletes from the same age group perform similarly but that there is a difference between different age groups, young athletes and the older athletes performed differently in the Cogstate sport test.

A study done by Whitford et al. (2007) recorded significant structural changes within the brain during the adolescent period, indicating that changes and different levels of performance in cognitive function ought to be expected from one age group to the next.<sup>[40]</sup> Baseline testing is suggested to be administered regularly, not just to ensure test-retest reliability, due to time, but to accommodate for these neurological changes that occur with age, that seemingly affect cognitive test performance.<sup>[17,36]</sup>

In Table 4.20 the two-way ANOVA results show that a statistically significant difference for males ( $p = 0.01$ ) and females ( $p = 0.00$ ) was found. However, there was no statistically significant difference ( $p = 0.23$ ) found between sexes nor was there a statistically significant interaction ( $p = 0.25$ ) found between sex and age.

This suggests that there was no statistically significant difference between the two sexes, but there was a statistically significant difference between age groups within the same sex. The assumption drawn here implies that sex may not be the major factor in baseline performance but that age plays an important role in the changes observed in baseline performance.

Another potential concern that has been raised in the current literature was the influence of group testing on neuropsychological performance.<sup>[16]</sup> Testing sessions for the Cogstate sport test were conducted within a group environment for the current study. Group sizes varied from 10 to 25 individuals per group session, each session was administered by the researcher.

A study done by Vaughan et al. (2014) investigated the difference between group testing environments and individual testing environments. Test results found in this study by Vaughan et al. (2014) reported no statistically significant difference between

the two testing environments amongst adolescents, given the testing procedures remained consistent and controlled.<sup>[16]</sup>

In conclusion, when administered consistently and in a controlled manner, the testing environment should have no significant effect on baseline values.<sup>[16]</sup> The participant's sex does not seem to be a determining factor in baseline reliability in the current study. However, age does seem to play a significant role in the differences observed between 2016 and 2017 baseline values for the Cogstate sport test. This should be considered while implementing a concussion management initiative at any high school. Again, annual pre-season baseline testing could help control for the changes seen in cognitive performance as the athlete ages. The athlete's concussion profile, history, and available baseline data, should grow along with the maturing athlete to ensure continued safe play and decision making in his or her athletic career.

### **Summary and implication of findings for objective three:**

- No statistically significant differences between baseline values for 2016 and 2017 were observed amongst participants of the same age group.
- A statistically significant difference was seen between different age groups for both sexes.
- No statistically significant difference was observed between sexes.
- No statistically significant interaction was evident between sex and age.
- When administered consistently and in a controlled manner the testing environment should have no significant effect on baseline values.
- The participant's sex does not seem to be a determining factor in baseline reliability in the current study.
- Age seems to play a significant role in the differences observed between 2016 and 2017 baseline values for the Cogstate sport test.
- The changes brought on by maturation should be considered while implementing a concussion management initiative at any high school. Regular baseline testing could control for the rate of change in cognitive performance.

## 5.4 Conclusion

A concussion is a common injury reported in contact or high velocity hitting sports,<sup>[2,3,25]</sup> and it is deemed a complex, unpredictable and a highly individualized injury.<sup>[6,20,22]</sup> It can manifest in an array of signs and symptoms along with cognitive deficits, in various combinations, making it significantly hard to diagnose and manage.<sup>[6,20,22]</sup>

Without proper diagnosis, a concussion may go unnoticed, which could lead to catastrophic outcomes like second impact syndrome or severe long-term cognitive impairments.<sup>[4,11,13]</sup> This is concerning considering many institutions still lack the proper knowledge on concussion management, and it is especially a problem amongst schools as the developing brain had been noted to be more susceptible to concussions.<sup>[4]</sup>

The baseline method had been suggested to be the best approach to manage a concussive injury.<sup>[3]</sup> Available baseline data could help ensure that an informed diagnosis and return to play decision be made, due to the fact that individual patient information is available for comparison.<sup>[3]</sup> Standardized tests, such as neuropsychological tests and oculomotor function tests, have ensured its role in the management of concussion within the clinical setting and can be implemented to obtain baseline data.<sup>[11]</sup>

Males show a higher willingness to partake in high risk or contact sports than females. This may be a plausible explanation for the higher number of male participants (55.55% and 60.71%) than female participants (44.44% and 39.28%) for the KD test and Cogstate sport respectively.<sup>[13]</sup>

The adherence to baseline testing showed a decline with an increase in age.<sup>[41]</sup> The two youngest age groups in the study made up 70.37% and 71.42%, respectively, of the total participation group in the KD test and Cogstate sport test. The simple practicality that the parents had a bigger influence on the day to day schedule of the younger age groups than on the older age groups could be a possible reason for the trend in program adherence.<sup>[42]</sup>

#### **5.4.1 The conclusions drawn for the King-Devick test.**

The KD test is a visual performance measure and proven to be effective in diagnosing signs and symptoms associated with concussion in the acute phase.<sup>[30,31,33]</sup> The KD test is capable of assessing specific neurological function, which in turn is more evidence-based than subjective symptom checklists.<sup>[29]</sup>

A statistically significant difference ( $p = 0.0001$ ) between baseline values from 2016 and 2017 was observed, although a small effect size ( $D: -0.376$ ) was reported for this difference. Less time was taken to complete the KD test baseline in 2017 (mean - 46.11s) than what it did in 2016 (mean - 49.13s) for the total group.

Currently, research reports that a three-second deviation from baseline is still acceptable but that five seconds or slower is an indication of a concussion.<sup>[2,18,19,29]</sup> The 3.02s improvement observed between 2016 to 2017 baseline values in the current study suggest that there is a potential for misdiagnoses when using a year old baseline, with the five-second deviation as a reference.<sup>[2,18,19,31]</sup> Although, the improvement observed in baseline values are consistent with previous research, the implication of this improvement, and the fact that it may have the potential to surpass the suggested norm for standard deviation had yet to be addressed in research.

The test-retest reliability between 2016 and 2017 baseline values was found to be low (0.542) in the current study. Test-retest reliability seems to be negatively affected by the amount of time passed, rendering the test-retest reliability below clinically acceptable values (0.6) after a single year.<sup>[44]</sup> These results confirm that each new sporting season warrants a new pre-season baseline and that the previous season's baseline would not aid in the proper clinical management of a concussive injury.<sup>[16]</sup>

The statistically significant difference seen in the total participant group ( $p = 0.004$ ) is between sexes and not between participants of the same sex. Current literature supports this finding by suggesting individual baseline testing should be conducted since females and males cannot be accurately assessed on the same norms.<sup>[26,36]</sup>

There was no statistically significant difference for KD baseline values from one year to the next for the three oldest age groups. However, a statistically significant difference ( $p = 0.044$ ) was found between baseline values after one year for those born in 2002 (age 13 to 15), the youngest age group.

The current study concludes that there is a difference in cognitive ability between the two sexes and the cognitive development is more prominent in the younger spectrum of adolescence, according to the results of the KD test.<sup>[17,20,36]</sup> The implementation of the KD test warrants proper baseline testing, as no normative data for adolescents had been established yet.<sup>[32,33]</sup>

#### **5.4.2 The conclusions drawn for the Cogstate Sport test**

Neuropsychological testing is described as the cornerstone of concussion management.<sup>[3,5,6,12,23]</sup> The Cogstate program is a brief neuropsychological test battery specifically designed to measure cognitive function over repetitive short intervals and to track any cognitive changes during these time intervals.

The results showed a statistically significant difference between baseline values from 2016 to 2017 for task one ( $p = 0.003$ ) and task two ( $p = 0.005$ ). However, no statistically significant difference was reported for task three ( $p = 0.703$ ) and task four ( $p = 0.149$ ) between baseline values from 2016 to 2017. A small effect size was found for the differences found between baseline values from one year to the next for each of the four tasks.

No statistically significant differences ( $p = 0.326$  to  $0.064$ ) were found between 2016 to 2017 baseline values amongst participants within the same age groups. However, a statistically significant difference ( $p = 0.001$ ) was found between 2016 and 2017 baseline values between the different age groups. This suggests that athletes from the same age group perform similarly but that there is a difference between different age groups.

A statistically significant difference between 2016 and 2017 baseline values was found amongst males participants ( $p = 0.006$ ) and amongst females participants ( $p = 0.003$ ). However, there was no statistically significant difference ( $p = 0.262$ ) found between the two sexes.

The conclusion is that sex may not be the major factor in baseline performance but that age plays the main role in the changes observed in baseline performance for the Cogstate test. It had previously been found that males and females perform differently

on neuropsychological tests,<sup>[15]</sup> however, the mean values and differences observed in the current study, between the sexes, showed similar trends and values.

A difference in task performance between age groups was noted in the current study. Each task test a different cognitive domain, it might be worth considering the 'neurological pruning', a period of dynamic structural changes within the neurological structure and cognitive functioning of the brain, that had been suggested during the adolescent period.<sup>[20]</sup> More insight might aid in the diagnosis of a concussion and the management thereof if it is known which cognitive domain at a certain age might be more affected by a concussive injury. The implication of this had yet to be addressed in the currently available research on adolescent athletes.

The low to poor test-retest reliability shown between 2016 baseline values and 2017 baseline values for the current study are below clinical standards (0.6), suggesting that a year old baseline might not be the best measure for proper concussion management. The low test-retest reliability in the current study could be attributed to the time elapsed between testing sessions. A study done by Bruce et al. (2016) found that test-retest reliability seemed to decline with time, but that regular baseline testing may have the potential to improve the test-retest reliability.<sup>[44]</sup>

A plausible reason for the observed variability in test-retest reliability scores, observed with elapsed time, could be the significant structural changes seen in the adolescent brain, representing the natural growth and development that takes place during adolescence.<sup>[17,18,20,36]</sup>

### **5.4.3 Final thoughts regarding the conclusions drawn in the current study.**

Given the variability of the natural maturation process, and that not all chronological maturation follow the same biological maturation, it can be suggested that an individualized baseline would ensure a more accurate diagnosis than using normative values.<sup>[16,18]</sup> If we were to use the norm the individual with the minimum score would be misdiagnosed and the individual with the higher score would be prematurely sent back to play.<sup>[16,44]</sup>

The current study would suggest that timing and planning plays an important role in the holistic approach to effective concussion management, and would propose that periodization is considered in future research and concussion initiatives. Although schools and sporting codes vary in their pre-season and in-season duration and time of year, it still proves to be a variable within the school's control.

A study done by Whitford et al. (2007) recorded significant structural changes within the brain during the adolescent period, indicating that changes and different levels of performance in cognitive function ought to be expected from one age group to the next.<sup>[39]</sup> Baseline testing is suggested to be administered regularly, not just to ensure test-retest reliability, due to time, but to accommodate for these neurological changes that occur with age, that seemingly affect cognitive test performance.<sup>[17,36]</sup>

The athlete's concussion profile, history, and available baseline data, should grow along with the maturing athlete to ensure continued safe play and decision making in his or her athletic career.

## **5.5 Limitations and future recommendations**

This section will attempt to highlight some of the study limitations and to suggest potential areas that were noted in this study, to warrant more research in the future.

### **5.5.1 The limitations identified in the current study.**

The literature suggests that a participant with a concussion history or that had sustained a previous concussive injury tend to perform worse than their non-concussed peers in a neurophysiological test.<sup>[5,18,19]</sup> For this study, the individual concussion history was not documented and therefore could not be considered.

Another limitation that was noted for this study was the potential of learning effects for the KD test. Signs of a learning effect between the first and second test trial in certain studies have been noted.<sup>[2,31]</sup> In order to help counter this learning effect, two sets of test cards have been developed to be used interchangeably.<sup>[31]</sup> This study did not control for the potential learning effect, the same set of test cards were used for 2017 as was used in 2016.

It is challenging to identify an accurate statistically significant difference when the sample size is small, and the sub-groups are smaller. The highly individualized data that did not follow a normal distribution only adds to the challenge. Larger sample sizes are recommended for future endeavours similar to this study, especially since the data sets will remain in the non-parametric category.

### **5.5.2 New potential research questions identified from the current study.**

The periodization, planning, and timing of baseline testing during a sporting seasons are important factors in the holistic approach to effective concussion management.

More clarity is needed on the difference in managing a concussive injury between sexes and amongst different age groups. If proper, reliable norms cannot be established by future research it should be considered to look into the potential of prioritizing baseline testing in the current legislation. If suggested to be useful in the



management of concussion, why not prioritize it in an attempt to safeguard the mental health and future of youth athletes?

In the current study it was noted that different age groups performed differently in the four task, cognitive domains, of the Cogstate sport test. Understanding the effect of the 'neurological pruning', a period of dynamic structural changes within the neurological structure and cognitive functioning of the brain might aid in the diagnosis of a concussion and the management thereof. If it is known which cognitive domain at a certain age might be more affected by a concussive injury, the interpretation of the Cogstate sport test results could be tailored to a specific age group.

In conclusion, it is recommended that these trends be investigated with larger sample sizes, especially for both sub-groups of sex and age. It would also be wise, and interesting to investigate these trends with the use of other modalities/assessment tools.

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## Appendix A: World Rugby concussion guidance, 2015

<http://playerwelfare.worldrugby.org/?documentid=158>



**WORLD RUGBY** *Putting players first*

Concussion guidance

### Introduction

This World Rugby Concussion Guidance document has been developed to provide guidance and information to persons involved in the non-elite level of the game of Rugby regarding concussion and suspected concussion.

Individual member Unions are strongly encouraged to develop their own guidelines and policies, and must use this Concussion Guidance as minimum standards.

These guidelines apply to all male and female Rugby players including adults (over 18 years), adolescents (18 and under) and children (12 and under). Unions can adjust these age levels upwards at their discretion.

### CONCUSSION FACTS

- A concussion is a traumatic **brain injury**.
- All concussions are **serious**.
- Concussions can occur **without loss of consciousness**.
- All athletes with any new symptoms following a head injury
  - must be removed from playing or training
  - must not return to playing or training until symptom free or until all concussion-related symptoms have cleared or have returned to pre-concussion level
  - must complete a Graduated Return To Play programme
  - should be assessed by a medical practitioner
- Specifically, return to play or training on the day of a **concussion or suspected concussion is forbidden**.
- **Recognise and Remove** to help prevent further injury or even death.
- **Head injuries can be fatal - do not return to play if symptoms persist.**
- Most players with concussion recover with physical and mental rest.

World Rugby strongly recommends that all players seek the highest level of medical care available following concussion or suspected concussion (see definition of Advanced Care below).



## Appendix B: SARU regulation on concussion, 2015

<http://images.supersport.com/content/CONC.pdf>

### SARU REGULATION ON CONCUSSION

Concussion is a brain injury caused by trauma that transmits force to the brain either directly or indirectly and results in impairment of brain function. A player can sustain a concussion without losing consciousness. Concussion is associated with a wide spectrum of signs and symptoms that resolve sequentially. Concussion reflects a functional rather than a gross structural injury and standard neuro-imaging typically appears normal.

#### 1. SARU's stance on concussion

SARU views concussion extremely seriously. SARU therefore insists that every role player<sup>1</sup>, involved in all rugby played within South Africa, gives the highest level of attention to the most current evidence-based, internationally accepted, best practice standards of prevention, identification, treatment and management of players suspected of having a concussion or those who have been diagnosed with a concussion.

#### 2. Role of the SARU

SARU is a Member Union of World Rugby. As such, SARU is required to implement Concussion Regulations that are aligned with the World Rugby Medical Regulations as set out below in the following Clauses. SARU has also contributed to the development of the World Rugby's concussion protocols.

#### 3. WORLD RUGBY CONCUSSION REGULATIONS

##### **REGULATION 10 – MEDICAL**

*Concussion is a brain injury, which is serious and can be suffered by a Player of any age.*

*Concussion and suspected concussion must be taken extremely seriously by all those involved in the Game in order to protect the safety, health and welfare of Players.*

*Extra caution must also be taken with children and adolescents who have a greater risk of concussion and associated complications.*

---

<sup>1</sup> 'Role players' include but are not limited to coaches, referees, medical staff, parents, team management, players and match officials.

Approved by the General Meeting on 11 December 2015.

## Appendix C: Letter of approval from MSc committee



MSc Committee  
School of Medicine  
Faculty of Health Sciences

MSc Committee  
31 August 2017

Dr R Grant  
Department of Physiology  
Faculty of Health Sciences

Dear Dr,

**Ms J Coetzer, Student no 29373350**

Please receive the following comments with reference to the MSc Committee submission of the abovementioned student:

<b>Student name</b>	Ms J Coetzer	<b>Student number</b>	29373350
<b>Name of study leader</b>	Dr R Grant		
<b>Department</b>	Physiology		
<b>Title of MSc</b>	Reliability of baseline concussion test results in youth athletes from two consecutive sport seasons		
<b>Date of first submission</b>	November 2014		
<b>October 2015</b>	• Thank you for submitting the revised protocol		
<b>August 2017</b>	• Thank you for submitting the documents required for a title change request. • Thank you for submitting the ethics approval certificate. • The title change has been approved.		
<b>Decision</b>	This protocol has been approved. Ethics approval has been obtained. The internal and external examiners can be nominated six months prior to the submission of the dissertation. Please ensure that the CV of the examiners includes: supervision, examination and publication records.		

Yours sincerely



Dr Marleen Kock  
Chair: MSc Committee

## Appendix D: Ethical approval

A new ethical approval certificate was requested due to a title change. The original ethical approval obtained on 26/05/2016 is also attached following the current Ethical approval in Appendix D.

The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 22 May 2002 and Expires 03/20/2022.
- IRB 0000 2235 IORG0001762 Approved dd 22/04/2014 and Expires 03/14/2020.



UNIVERSITEIT VAN PRETORIA  
UNIVERSITY OF PRETORIA  
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences Research Ethics Committee

8/02/2018

### Approval Certificate Amendment

(to be read in conjunction with the main approval certificate)

Ethics Reference No.: 155/2016

Title: Reliability of baseline concussion test results in youth athletes from two consecutive sports seasons.

Dear Jeanette Coetzer

The Amendment as described in your documents specified in your cover letter dated 7/12/2017 received on 21/01/2018 was approved by the Faculty of Health Sciences Research Ethics Committee on 22/01/2018.

- Title Change suggested by the MSc Committee and Extension of approval until 31/12/2018.

Please note the following about your ethics amendment:

- Please remember to use your protocol number (155/2016) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, or monitor the conduct of your research.
- The Amendment will be ratified at the meeting of 28/02/2018

Ethics amendment is subject to the following:

- The ethics approval is conditional on the receipt of **6 monthly written Progress Reports**, and
- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

Dr R Sommers; MBChB; MMed (Int); MPharMed; PhD  
Deputy Chairperson of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health).

☎ 012 356 3085    ✉ [manda.smith@up.ac.za](mailto:manda.smith@up.ac.za) / [fhsethics@up.ac.za](mailto:fhsethics@up.ac.za)    🌐 <http://www.up.ac.za/healthethics>  
✉ Private Bag X323, Arcadia, 0007 - Tswelopele Building, Level 4, Room 60 / 61, 31 Bophelo Road, Gezina, Pretoria

\*\* Kindly collect your original signed approval certificate from our offices, Faculty of Health Sciences, Research Ethics Committee, Tswelopele Building, Level 4-60

The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 22 May 2002 and Expires 20 Oct 2016.
- IRB 0000 2235 IORG0001762 Approved dd 22/04/2014 and Expires 22/04/2017.



UNIVERSITEIT VAN PRETORIA  
UNIVERSITY OF PRETORIA  
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Faculty of Health Sciences Research Ethics Committee

26/05/2016

Approval Certificate  
New Application

Ethics Reference No.: 155/2016

Title: Investigation of concussion severity and return to play in high school athletes from different sport types

Dear Jeanette Coetzer

The New Application as supported by documents specified in your cover letter dated 19/05/2016 for your research received on the 19/05/2016, was approved by the Faculty of Health Sciences Research Ethics Committee on its quorate meeting of 25/05/2016.

Please note the following about your ethics approval:

- Ethics Approval is valid for 2 years
- Please remember to use your protocol number (155/2016) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, or monitor the conduct of your research.

Ethics approval is subject to the following:

- The ethics approval is conditional on the receipt of **6 monthly written Progress Reports**, and
- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

*\*\* Kindly collect your original signed approval certificate from our offices, Faculty of Health Sciences, Research Ethics Committee, Tswelopele Building, Level 4-59*

Dr R Sommers; MBChB; MMed (Int); MPharMed, PhD  
Deputy Chairperson of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria

*The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).*

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## Appendix E: Concussion indemnity form and letter to parents (2016 + 2017)



Geagte Ouers  
24 Oktober 2016

### HANTERING VAN KONKUSSIE

Konkussie is 'n sportbesering waar die breinweefsel beseer word. Dit is 'n ernstige en onvoorspelbare besering wat die normale breinfunksie van 'n persoon negatief beïnvloed. As konkussie verkeerd hanteer word en die beseerde dalk 'n tweede hou teen die kop kry (voor die eerste geval herstel het), loop die beseerde die gevaar om permanente skade op te doen.

Registrasie – Oktober 2016 tot Januarie 2017	Bekom 'n konkussiebrief (Sportburo/ “communicator”)
	Voltooi die brief en besorg terug aan Jeanette Coetzer in die Sportburo
	<b>Koste beloop R100 per kind</b> (kontant betaalbaar by Jeanette Coetzer)
	Datums van basilyntoetse sal in Januarie 2017 bekend gemaak word.
Basilyntoetse - Januarie to Februarie 2017	Bestaan uit twee toetse wat tydens twee verskillende sessies afgelê moet word.
	<b>Ogghendessie</b> - King-Devick Toets. Tye: 06:30 – 07:20 by die Sportburo
	<b>Twee middagsessie</b> – Axon-sport (Rekenaartoets) Tye:(1)14:15 – 15:00 of (2)15:00 – 15:45 in K45 (Klaskamer-Waterkloof) Kies slegs een sessie in die tydgleef wat jou pas.
	Bespreek sessies vooraf by Jeanette Coetzer in die Sportburo.

Enige leerder betrokke by sport is welkom om vir die konkussieprogram te registreer. Rugby-en hokkiespelers is vriendlik verplig om aan die program deel te neem. Enige moontlike konkussiegeval moet so spoedig moontlik of binne die eerste 48 uur by die Department Medies en Sportwetenskap in die Sportburo aangemeld word. Enige leerder wat deel van die program is, bekom die diens van die konkussie-dokter gratis.

Ons stuur outomaties 'n doktersbrief per e-pos na die betrokke onderwysers wat verduidelik dat die leerder konkussie het en indien daar enige akademiese agteruitgang plaasvind, moet die leerder 'n tweede geleentheid kry. Dié reëling is veral belangrik in geval van toetse en eksamen.

Kontak Jeanette Coetzer by die sportburo (072 305 8535 / [jeanette.coetzer@klofies.co.za](mailto:jeanette.coetzer@klofies.co.za)) vir navrae.

Groete.

Voltooi asseblief die onderstaande brief en besorg dit aan Jeanette Coetzer by die Sportburo.

### KONKUSSIE-VRYWARING

NAAM EN VAN (ouer): .....

SEL NR (ouer): .....

E-POSADRES (ouer): .....

SPORT (kind): .....

GEBOORTEJAAR (kind): .....

Ek bevestig hiermee dat ek, die ouer/voog van, \_\_\_\_\_, (kind se naam en van) die volgende opsies aangaande konkussie bestudeer het. Ek bevestig dat ek die aangehegte brief gelees en verstaan het.

<p>Ek verkies om nie my kind aan die program te laat deelneem nie. Ek verstaan dat my kind mediese sorg benodig in die geval van konkussie. Ek sal 'n dokter van my keuse buite die skool raadpleeg. <b><u>Ek onderneem om 'n afskrif van die doktersbrief by die skool in te dien asook 'n bewys van wanneer my kind volgens die dokter weer mag terugkeer na sy/haar sport. Indien die twee dokumente nie ingehandig word nie, sal deelname geweier word.</u></b></p>	
<p>Ek aanvaar Hoërskool Waterkloof se konkussieprogram en wil graag betrokke raak. Ek weet dat die koste hieraan verbonde R100 is. Met dié keuse besef ek dat nie ek (as ouer) of my kind se afrigter 'n besluit mag neem oor wanneer my kind na sy/haar sport mag terugkeer nie, maar slegs die mediese dokter.</p> <p>Heg asb. die R100 aan met terugbesorging. Geen brief sal aanvaar word sonder betaling nie.</p>	

Die skool se Departement Medies en Sportwetenskap en die Departement Sportgeneeskunde van die Universiteit van Pretoria doen saam navorsing oor konkussie. Leerders se inligting gaan aan die Universiteit vir navorsing beskikbaar gestel word. Leerders se identiteit sal nie bekend gemaak word nie.

\_\_\_\_\_ GETEKEN OP DIE \_\_\_\_ DAG VAN \_\_\_\_\_ 20\_\_

HANDTEKENING (ouer)

## After-Injury Test Report

### Test Information

CodeName: HKWBEZUIDENHOUTD1999  
 Birth Year: 1999  
 Gender: Male  
 Age: 15  
 Handedness: Right  
 Test Date: 30 May 2014  
 Test Time: 07:31 AM  
 Test Duration: 561.8 seconds  
 Test Type: After-Injury  
 Baseline Test Date: 07 Feb 2014  
 Test ID: 132847  
 Team: Van-Der-Spy

### Integrity Checks

Detection Accuracy > 80% (95%) ✓  
 Identification Accuracy > 80% (97%) ✓  
 One Card Learning Accuracy > 53% (69%) ✓  
 Detection Speed < Identification Speed ✓  
 Detection Speed < One Back Speed ✓

### Clinical Symptom Checklist

SCAT Baseline Symptom Total : 11  
 SCAT After-Injury Symptom Total : 2  
 Symptoms : neck pain 2  
 Other symptoms: none  
 Concussion History  
 How many times have you been concussed? 2 times  
 When were you injured, 6 days ago, tracked out (unconscious)? Yes  
 After you were injured, did you have trouble remembering things which happened around the time of your injury? No  
 After you were injured, did you have any trouble sleeping? Yes  
 Have you participated in any sport training or other exercise since you were injured? Yes

### Cognitive Test Results

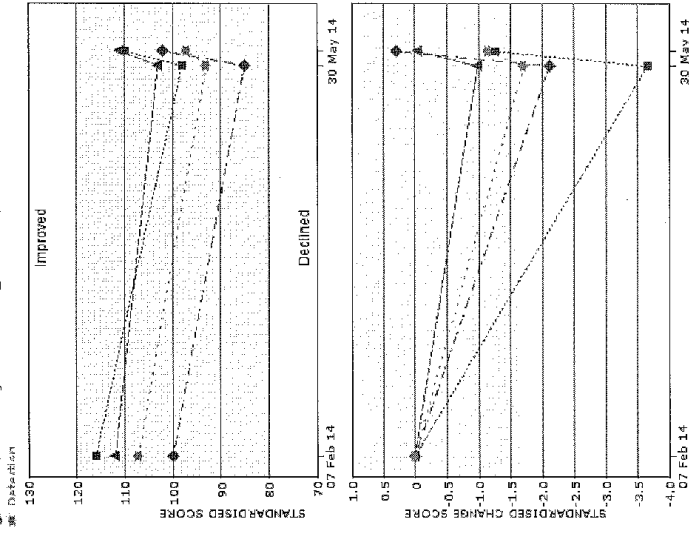
	Baseline 07 Feb 2014	After-Injury 30 May 2014	Significant Decline 5
Detection	107.6	97.9	Yes 9.7 (N<7.7)
Speed 1	242 ms	276 ms	
Accuracy 2	97.30	94.70	
Hits 3	36	36	
Misses 4	1	2	
Anticipations 4	1	1	
Identification	112.2	111.9	No 0.3 (N<14.5)
Speed 1	370 ms	372 ms	
Accuracy 2	88.20	96.80	
Hits 3	30	30	
Misses 4	4	1	
Anticipations 4	0	0	
One Card Learning	100.8	102.9	
Speed 1	577 ms	592 ms	
Accuracy 2	66.70	69.0	
Hits 3	28	29	
Misses 4	14	13	
Anticipations 4	0	0	
One Back	116.4	110.3	No 6.1 (N<12.0)
Speed 1	416 ms	467 ms	
Accuracy 2	93.90	91.20	
Hits 3	31	31	
Misses 4	2	3	
Anticipations 4	0	0	

1. A higher value indicates a slower response.  
 2. A higher value indicates a better response.  
 3. A higher value indicates a better performance.  
 4. A higher value indicates a better response.  
 5. Threshold is 1.65 standard deviations computed from age-based within subject standard deviation around a mean of 100, with a standard deviation of 20. All data is compared to age-matched normative baseline.

### Result Summary

This athlete displayed a decline in cognitive test performance from their baseline test, and also reported symptoms of concussion at the time of taking this after-injury test. Another test should be taken after 24 hours rest. If cognitive impairment or symptoms do not resolve, this athlete should be evaluated by a neurological specialist.

◆ One Card Learning    ■ One Back    ▲ Identification



Wait and Retest



## Appendix G: Return to play protocol

### The Graduated Return to Play (GRTP) Protocol

GRTP Protocol – each Stage AFTER the stand-down period is a minimum of 24 hours for *players 16 years old and above* and 48 hours in *players 15 years old or younger*




Stage	Rehabilitation	Objective	Exercise Allowed
1	Minimum age-appropriate rest period	Recovery	<ul style="list-style-type: none"> <li>Complete body and brain rest without symptoms</li> </ul>
2	Light aerobic exercise	Increase heart rate	<ul style="list-style-type: none"> <li>Light jogging for 10-15 minutes, swimming or stationary cycling at low to moderate intensity.</li> <li>No resistance training.</li> <li>Symptom free during full 24/48-hour period.</li> </ul>
3	Sport-specific exercise	Add movement	<ul style="list-style-type: none"> <li>Running drills.</li> <li>No head impact activities</li> </ul>
4	Non-contact training drills	Exercise, coordination, and cognitive load	<ul style="list-style-type: none"> <li>Progression to more complex training drills, e.g. passing drills.</li> <li>May start progressive resistance training.</li> <li>Player <b>MUST</b> be medically cleared at the end of this Stage before going to Full-contact training or Stage 5</li> </ul>
5	Full Contact Practice	Restore confidence and assess functional skills by coaching staff	<ul style="list-style-type: none"> <li>Normal rugby training activities</li> <li>If player remains sign and symptom-free for the full 24/48 hours, they then move onto Stage 6</li> </ul>
6	Return to Play	Recover	<ul style="list-style-type: none"> <li>Player rehabilitated and can be progressively re-introduced into full match play</li> </ul>

#### Notes:

- *a player may only start the GRTP process once cleared by a medical doctor and all symptoms have cleared*
- *a player may only progress to the next stage if no symptoms occur during or after exercise in each stage*
- *a player must again be cleared by medical doctor before starting full-contact training*



Summary of Return to Play Criteria for Rugby

AGE GROUP	COMPULSORY REST PERIOD POST CONCUSSION		GRTP		NUMBER OF MISSED FULL WEEKS
Players aged 15 or younger	2 weeks and symptom free	<p><b>Caution!</b> Return to play protocol should be started only if the player is symptom free and off medication that modifies symptoms of concussion</p>	4 Stage GRTP with progression every 48 hours if no symptoms. Total GRTP days = 8 days.	<p><b>Caution!</b> Contact Sport should be authorized only if the player is symptom free and off medication MEDICAL CLEARANCE REQUIRED</p>	Earliest Return to play = 2 weeks rest post injury + 8 days GRTP (Play - Day 23 post injury)
	2 weeks and symptom free		4 Stage GRTP with progression every 24 hours if no symptoms. Total GRTP days = 4 days.		Earliest Return to play = 2 weeks rest post injury + 4 days GRTP (Play - Day 19 post injury)
Players aged 16, 17, 18 & 19	1 day and symptom free	4 Stage GRTP with progression every 24 hours if no symptoms. Total GRTP days = 4 days.	Earliest Return to play = 1 day rest post injury + 4 day GRTP (Play - Day 6 post injury)		
Players aged 20 & over					
<p> Any player with a second concussion within 12 months, a history of multiple concussions, players with unusual presentations or prolonged recovery should be assessed and managed by health care providers (multidisciplinary) with experience in sports-related concussions. It is recommended that if this expertise is unavailable then as a minimum the player should be managed using the protocol from the lower age group i.e. 1. 'Players 20 and over' uses the 'Players 16-19' protocol 2. 'Players 16-19' uses the 'Players 15 and younger' protocol 3. For 'Players 15 and younger' the minimum rest period should be <u>doubled</u>. However, the medical doctor clearance is non-negotiable and must always be provided before entering the GRTP and before starting full-contact training, regardless of who is available to manage or monitor the GRTP process.</p>					



## Appendix H: Declaration by principle investigator (Helsinki 2013)

### DECLARATION BY PRINCIPAL INVESTIGATOR AND SUB-INVESTIGATOR

**Name:** Jeanette Coetzer

**Student Number:** 29375330

**Title:** Reliability of baseline concussion test results in youth athletes from two consecutive sport seasons.

**Degree:** MSC Sport Science

1. I have read and understood item 1.5.5 on page 5 and section 3 (pages 14-20) "Responsibility of the Principal Investigator (PI) and participating investigators of the *Clinical Trials Guidelines of the Department of Health: 2000*
2. I have notified the South African regulatory authority of any aspects of the above guidelines with which I do not / unable to comply (If applicable, this may be attached to this declaration).
3. I have thoroughly read, understood, and critically analysed (in terms of the South African context) the protocol and all applicable accompanying documentation, including the investigator's brochure, patient information leaflet(s) and informed consent forms(s).
4. I will conduct the trial as specified in the protocol.
5. To the best of my knowledge, I have the potential at the site(s) I am responsible for, to recruit the required number of suitable participants within the stipulated time period.
6. I will not commence with my role in the trial before written authorizations from the relevant ethics committee (s) as well as the South African Medicines Control Council (MCC) have been obtained.
7. I will obtain informed consent from all participants or if they are not legally competent, from their legal representatives.
8. I will ensure that every participant (or other involved persons, such as relatives), shall at all times be treated in a dignified manner and with respect.
9. Using the broad definition of conflict of interest below, I declare that I have no financial or personal relationship(s) which may inappropriately influence me in carrying out this clinical trial.  
*Conflict of interest exists when an investigator (or the investigator's institution), has financial or personal relationships with other persons or organizations that inappropriately influence (bias) his or her actions)\**  
\*Modified from: Davidhoff F, et al. Sponsorship, Authorship and Accountability. (Editorial) JAMA Volume 286 number 10 (September 12, 2001)
10. I have not previously been involved in a trial which has been closed due to failure to comply with Good Clinical Practice.
11. I have not previously been the principal investigator at a site which has been closed due to failure to comply with Good Clinical Practise (\*Attach details)
12. I will submit all required reports within the stipulated time-frames.

Signature: 

Date: 24 / 07 / 2017.

Witness: 

Date: 24 / 07 / 2017

## Special Communication

# World Medical Association Declaration of Helsinki

## Ethical Principles for Medical Research Involving Human Subjects

World Medical Association

Adopted by the 18th WMA General Assembly, Helsinki, Finland, June 1964, and amended by the:  
 29th WMA General Assembly, Tokyo, Japan, October 1975  
 35th WMA General Assembly, Venice, Italy, October 1983  
 41st WMA General Assembly, Hong Kong, September 1989  
 48th WMA General Assembly, Somerset West, Republic of South Africa, October 1996  
 52nd WMA General Assembly, Edinburgh, Scotland, October 2000  
 53rd WMA General Assembly, Washington, DC, USA, October 2002 (Note of Clarification added)  
 55th WMA General Assembly, Tokyo, Japan, October 2004 (Note of Clarification added)  
 59th WMA General Assembly, Seoul, Republic of Korea, October 2008  
 64th WMA General Assembly, Fortaleza, Brazil, October 2013

## Preamble

1. The World Medical Association (WMA) has developed the Declaration of Helsinki as a statement of ethical principles for medical research involving human subjects, including research on identifiable human material and data.

The Declaration is intended to be read as a whole and each of its constituent paragraphs should be applied with consideration of all other relevant paragraphs.

2. Consistent with the mandate of the WMA, the Declaration is addressed primarily to physicians. The WMA encourages others who are involved in medical research involving human subjects to adopt these principles.

## General Principles

3. The Declaration of Geneva of the WMA binds the physician with the words, "The health of my patient will be my first consideration," and the International Code of Medical Ethics declares that, "A physician shall act in the patient's best interest when providing medical care."
4. It is the duty of the physician to promote and safeguard the health, well-being and rights of patients, including those who are involved in medical research. The physician's knowledge and conscience are dedicated to the fulfillment of this duty.
5. Medical progress is based on research that ultimately must include studies involving human subjects.
6. The primary purpose of medical research involving human subjects is to understand the causes, development and effects of diseases and improve preventive, diagnostic and therapeutic interventions (methods, procedures and treatments). Even the

best proven interventions must be evaluated continually through research for their safety, effectiveness, efficiency, accessibility and quality.

7. Medical research is subject to ethical standards that promote and ensure respect for all human subjects and protect their health and rights.
8. While the primary purpose of medical research is to generate new knowledge, this goal can never take precedence over the rights and interests of individual research subjects.
9. It is the duty of physicians who are involved in medical research to protect the life, health, dignity, integrity, right to self-determination, privacy, and confidentiality of personal information of research subjects. The responsibility for the protection of research subjects must always rest with the physician or other health care professionals and never with the research subjects, even though they have given consent.
10. Physicians must consider the ethical, legal and regulatory norms and standards for research involving human subjects in their own countries as well as applicable international norms and standards. No national or international ethical, legal or regulatory requirement should reduce or eliminate any of the protections for research subjects set forth in this Declaration.
11. Medical research should be conducted in a manner that minimises possible harm to the environment.
12. Medical research involving human subjects must be conducted only by individuals with the appropriate ethics and scientific education, training and qualifications. Research on patients or healthy volunteers requires the supervision of a competent and appropriately qualified physician or other health care professional.


jama.com

JAMA Published online October 19, 2013

E1

Downloaded From: <http://jama.jamanetwork.com/> on 10/22/2013

Jeanette Coetzer  
18 Mei 2016.



# **Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities**

## **Preface**

The Internet has fundamentally changed the practical and economic realities of distributing scientific knowledge and cultural heritage. For the first time ever, the Internet now offers the chance to constitute a global and interactive representation of human knowledge, including cultural heritage and the guarantee of worldwide access.

We, the undersigned, feel obliged to address the challenges of the Internet as an emerging functional medium for distributing knowledge. Obviously, these developments will be able to significantly modify the nature of scientific publishing as well as the existing system of quality assurance.

In accordance with the spirit of the Declaration of the Budapest Open Access Initiative, the ECHO Charter and the Bethesda Statement on Open Access Publishing, we have drafted the Berlin Declaration to promote the Internet as a functional instrument for a global scientific knowledge base and human reflection and to specify measures which research policy makers, research institutions, funding agencies, libraries, archives and museums need to consider.

## **Goals**

Our mission of disseminating knowledge is only half complete if the information is not made widely and readily available to society. New possibilities of knowledge dissemination not only through the classical form but also and increasingly through the open access paradigm via the Internet have to be supported. We define open access as a comprehensive source of human knowledge and cultural heritage that has been approved by the scientific community.

In order to realize the vision of a global and accessible representation of knowledge, the future Web has to be sustainable, interactive, and transparent. Content and software tools must be openly accessible and compatible.

## **Definition of an Open Access Contribution**

Establishing open access as a worthwhile procedure ideally requires the active commitment of each and every individual producer of scientific knowledge and holder of cultural heritage. Open access contributions include original scientific research results, raw data and metadata, source materials, digital representations of pictorial and graphical materials and scholarly multimedia material.



## Appendix I: Declaration of investigator of commitments and responsibilities

**COMMITMENTS AND RESPONSIBILITIES OF PRINCIPAL/CO-INVESTIGATORS  
REQUIRED FOR RESEARCH THROUGH THE FACULTY OF HEALTH SCIENCES RESEARCH  
ETHICS COMMITTEE, UNIVERSITY OF PRETORIA**

**DECLARATION BY INVESTIGATOR:**

I agree to **personally** conduct or supervise the described investigation.

I understand as principal investigator that I am **totally responsible** for the study and am legally bound by the contract signed with the sponsor and **will not inappropriately delegate my responsibilities** to the rest of my study team.

I have **read and understand the information in the investigator's brochure**, including the potential risks and side effects of the drug.

I agree to **ensure** that all associates, colleagues, and employees assisting in the conduct of the study are informed about their obligations in meeting the above commitments, without relinquishing my total responsibility for the study.

I confirm that I am **suitably qualified and experienced** to perform and/or supervise the study proposed.

I agree to conduct the study in accordance with the relevant, current protocol and will only make changes in the protocol after approval by the sponsor and the Ethics Committee, except when urgently necessary to protect the safety, rights, or welfare of subjects.

I agree to inform any patients, or any persons used as controls, that the drugs are being used for investigational purposes and I **will ensure that the ICH GCP Guidelines and Ethics Committee requirements relating to obtaining informed consent are met.**

I agree to timeously reporting to the sponsor and Ethics Committee adverse experiences that occur in the course of the investigation according to the time requirements adopted by the Faculty of Health Sciences Research Ethics Committee, University of Pretoria.

I agree to maintain **adequate and accurate** records and to make those records available for inspection by the appropriate authorized agents, be it EC, FDA or sponsor agents.

I agree to comply with all other requirements regarding the obligations of clinical investigators and all other pertinent requirements in the Declaration of Helsinki and South African and ICH GCP Guidelines and am conversant with these guidelines.

I agree to inform the Ethics Committee in advance should I go on leave together with an agreed plan of action regarding an alternate principal investigator or sub-investigator to take responsibility in my absence.

I understand that the study may be audited at any time and that deviation from the principles in this declaration will be put before the Ethics Committee for action, which may include disqualification as an investigator and rehabilitation before being accepted as an investigator in other studies.

I confirm that there is no conflict of interest whatsoever in my participation in this study. I have no shares in the sponsoring company and my participation and interests are as defined in the financial agreement.


JEANETTE COETZER

NAME (Printed)


  
SIGNATURE OF PRINCIPAL INVESTIGATOR

24/07/2017  
DATE

## Appendix k: Letter of permission from Waterkloof High School



# HOËRSKOOI WATERKLOOF



18 Mei 2016

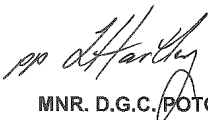
**WIE DIT MAG AANGAAN**

**Goedkeurings brief vir MSc studie protokol:  
"Investigation of concussion severity and return to play in high school  
athletes from different sport types."**

Hierdie brief bevestig dat Mev Jeanette Coetzer, toestemming van Hoërskool Waterkloof en alle betrokke partye het om die terrein en konkussieprogram te mag gebruik in haar navorsing.

Die MSc (Sport Science) protokol word goedgekeur om voort te gaan vanaf 2016 tot die voltooiing van haar studie.

Groete



**MNR. D.G.C. POTGIETER**  
**HOOF**

Posbus 25085, Monumentpark, Pretoria, 0105  
Tel: (012) 347 0277/8 | Faks: (012) 347 0279 | E-pos: kloffies@kloffies.co.za | www.kloffies.co.za

TOONAANGEWEND TOEKOMSGERIG

## Appendix J: Letter of permission from Waterkloof High School



HOËRSKOOI WATERKLOOF

18 Mei 2016

### WIE DIT MAG AANGAAN

**Goedkeurings brief vir MSc studie protokol:  
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athletes from different sport types."**

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Groete

**MNR. D.G.C. POTGIETER  
HOOF**

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Tel: (012) 347 0277/8 | Faks: (012) 347 0279 | E-pos: [klofies@klofies.co.za](mailto:klofies@klofies.co.za) | [www.klofies.co.za](http://www.klofies.co.za)

**TOONAANGEWEND TOEKOMSGERIG**

## Appendix K: The calculations and quantification of the Cogstate sport test.

(PDF – Embedded, please just double click to open the file)



### COGSTATE COMPOSITE COGNITIVE SCORES

Composite scores as a measure of overall cognitive performance, and they are calculated from all tasks in the battery.

In order to combine the task scores, each score at each assessment must be standardised (z-scores). This is done by standardising data against the baseline values from that sample (which acts as the control data for the study group) or from normative data.


#### Primary outcome measures for the CogState battery and the Completion criteria

Task name (Abbreviation in Data Extract)	Variable code	Unit of measurement	Completion Criteria
International Shopping List Task (ISLT)	cor	Number of correct responses	All 12 words were presented on all three trials, that is: sti =36
Detection Task (DET)	lms	Log <sub>10</sub> milliseconds	At least 27 responses made (presnt->27)
Identification Task (IDN)	lms	Log <sub>10</sub> milliseconds	At least 23 responses made (presnt->23)
One Back Memory Task (ONB)	lms	Log <sub>10</sub> milliseconds	At least 23 responses made (presnt->24)
Set Shifting (SETS)	err	Total number of errors	At least 90 responses made (sti->90)
Social-Emotional Cognition Task (SECT)	acc	Arcsine proportion correct	At least 36 responses made (presnt->36)
Continuous Paired Associate Learning (CPAL)	err	Total number of errors	All 8 targets correctly identified over the 7 learning trials (sti->56)
International Shopping List Task – Recall (ISRL)	cor	Number of correct responses	Task was attempted sti =12

Note: Completion criteria are included here, because scores that do not pass the completion criteria are not included in the composite score calculation.



## Appendix L: The King-Devick test cards and score sheets



**King-Devick Concussion Screening Test  
Score Sheet - Version 1**

Subject Name/ID Number: \_\_\_\_\_ Date of Birth: \_\_\_\_\_

Subject's Baseline Time: \_\_\_\_\_ Baseline Date: \_\_\_\_\_

Team/Sport: \_\_\_\_\_ Glasses/Contacts: \_\_\_\_\_

**Scoring King-Devick Test**

When testing, start the timer when the subject reads the first number on the test card and stop the timer when the subject reads the last number on the test card. Continue timing when the subject reads the first number on the second test card and stop the timer when the subject reads the last number on the test card. Repeat for third test card. Do not include the time between completing individual test cards. Total Time is the total testing time for all three test cards combined.

Answer Key Test Card I	Answer Key Test Card II	Answer Key Test Card III
2-5-8-0-7	3-7-5-9-0	5-4-1-8-0
3-7-9-4-6	2-5-7-4-8	4-8-3-5-9
5-3-1-6-4	1-4-7-6-3	7-5-4-2-7
7-9-7-3-5	7-9-3-9-0	3-2-6-9-4
1-5-4-9-2	4-5-2-1-7	1-4-5-1-3
6-5-5-7-3	5-3-7-4-8	9-3-4-8-5
3-1-8-6-4	7-4-6-5-2	5-1-6-3-1
5-3-7-5-2	9-0-2-3-6	4-3-5-2-7

**Establishing A King-Devick Test Baseline**

When establishing a Subject's initial Baseline Time, administer the King-Devick Test twice using the scoring instructions above. Use the fastest Baseline Total Time without errors of the two attempts below.

Baseline Attempt Time #1	Baseline Attempt Time #2	*Subject's Baseline Time
Total Time: _____	Total Time: _____	Total Time: _____
Total Errors: _____	Total Errors: _____	Total Errors: _____
Tester Initials: _____	Tester Initials: _____	Tester Initials: _____

**Testing After A Suspected Head Trauma**

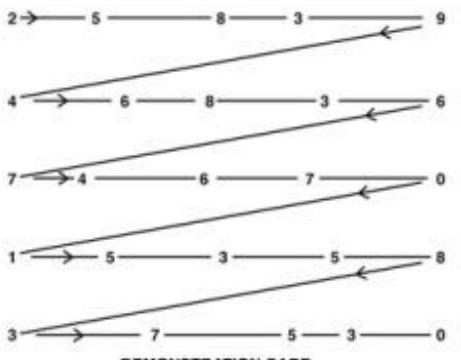

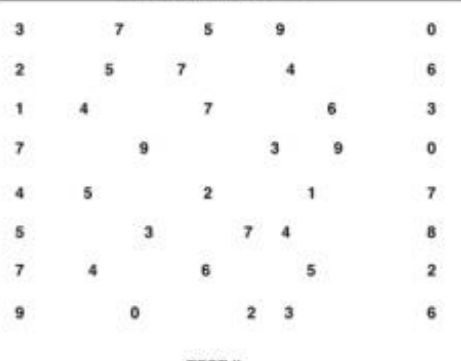

When testing after a suspected head trauma, the test should be administered once.

If the subject performs **SLOWER** than his/her baseline or has **INCREASED** errors, the subject should be **removed from play** and referred to a health care professional for additional evaluation.

If the subject performs **FASTER** than his/her baseline **WITHOUT** errors, the Total Time will become the subject's new Baseline Time.

Date: _____	Date: _____	Date: _____
Total Time: _____	Total Time: _____	Total Time: _____
Total Errors: _____	Total Errors: _____	Total Errors: _____
Tester Initials: _____	Tester Initials: _____	Tester Initials: _____
Comments: _____	Comments: _____	Comments: _____

King-Devick Test is for screening purposes only and any suspicion or indication of head trauma should be evaluated by a licensed professional. King-Devick Test (S-D) Trademark All Rights Reserved. © 2012, 2011, 2010, 1992. Unauthorized duplication is prohibited and a violation of applicable laws.

 <p style="text-align: center;"><b>DEMONSTRATION CARD</b></p>	 <p style="text-align: center;"><b>TEST I</b></p>
 <p style="text-align: center;"><b>TEST II</b></p>	 <p style="text-align: center;"><b>TEST III</b></p>

## Appendix M: Letter of support from statistician



**BIostatISTICS UNIT**

17 July 2017

### LETTER OF STATISTICAL SUPPORT

This letter confirms that J. Coetzer from the Department of Section Sports Medicine, Faculty of Health Sciences of the University of Pretoria discussed her project: "Reliability of baseline concussion test results in youth athletes from two consecutive sport seasons" with me. I confirm that I will assist with the statistical analysis of the study data.

#### Data analysis

The descriptive statistics mean, median, standard deviation and inter-quartile range, with 95% confidence intervals will be used to describe the test scores from the King-Devick (KD) and Cogstate tests. The variables gender and year of birth will be described using frequencies and proportions. Repeated analysis of variance will be used to test for significant differences between the 2016 and 2017 baseline KD test results, taking gender and year of birth into consideration. Repeated multivariate analysis of variance will be used to test if there are differences in psychomotor function, visual attention, working memory and visual learning scores between 2016 and 2017, taking gender and year of birth into consideration. Appropriate post-hoc tests will be conducted for both the ANOVA and MANOVA tests in order to determine where specific differences in scores occur. The intraclass correlation, as well as the Bland-Altman plot will be used to measure the agreement between 2016 and 2017 scores. Tests will be evaluated at 5% level of significance. All analysis will be done using STATA 14.

A handwritten signature in black ink, appearing to read 'C Janse van Rensburg'.

Name: C Janse van Rensburg  
Biostatistics Unit  
MRC Pretoria  
012 339 8529  
Charl.JansevanRensburg@mrc.ac.za



THE SOUTH AFRICAN MEDICAL RESEARCH COUNCIL  
1 Sandringham Road, Pretoria, 0002 | Private Bag X385, Pretoria 0601, South Africa  
Tel: +27 2012 339 8529 | e-mail: charl.jansevanrensburg@mrc.ac.za | Web: www.mrc.ac.za



## Appendix N: Short Curriculum Vitae on Publications

### MCC Format of CV's for Principal, Co and Sub-Investigators

#### Curriculum Vitae

<b>TITLE:</b>	Investigation of concussion severity and return to play in high school athletes from different sport types
<b>DEGREE:</b>	MSC SPORT SCIENCE
<b>1. Personal details:</b>	
<b>Name:</b>	JEANETTE COETZER
<b>Work Address:</b>	CNR BOEING AND SOLOMON MAHLANGU ELARDUS PARK, PRETORIA
<b>Site address(es):</b>	CNR BOEING AND SOLOMON MAHLANGU ELARDUS PARK, PRETORIA
<b>Contact information:</b>	
Telephone no.:	012 347 7707
Fax no.:	
Cell no.:	072 305 8535
E-mail address:	Jeanette.coetzer@klofies.co.za Coetzer.jen2gmail.com
<b>2. Academic and Professional Qualifications:</b>	
<b>Date</b>	<b>Qualification</b>
2011	(BA) MBK
2012	HONOURS SPORT SCIENCE
<b>3. Health Professionals Council of South Africa (HPCSA) registration number if applicable (or other health professions body registration particulars – e.g.. Nursing Council)</b>	
N/A	
<b>4. Current Personal Medical Malpractice Insurance Details:(Medical and Dental Practitioners)</b>	
N/A	

Appendix O: Declaration of storage

Protocol No. \_\_\_\_\_

**Principal Investigator(s) Declaration for the storage of research data and/or documents**

I, the Principal Investigator(s), Jeanette Coetzer  
of the following trial/study titled \_\_\_\_\_

Reliability of baseline concussion test results  
in youth athletes from two consecutive sport seasons.

will be storing all the research data and/or documents referring to the above mentioned  
trial/study at the following address: Boeing st and Solomon

Mahlangu, Pretoria, 0048


I understand that the storage for the abovementioned data and/or documents  
must be maintained for a minimum of 15 years from the commencement of this  
trial/study.

START DATE OF TRIAL/STUDY: January 2016

END DATE OF TRIAL/STUDY: October 2017

UNTIL WHICH YEAR WILL DATA BE STORED: 2032

Name Jeanette Coetzer

Signature 

Date 24 Julie 2017.

**Appendix P: Article draft to be submitted for publication.**

**Reliability of baseline concussion test results in youth athletes from two consecutive sports seasons**

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Word count for abstract: 250

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## **Abstract**

**Objective:** Determining the test-retest reliability of baseline values from two consecutive years.

**Design:** A prospective study, conducted over two years, where athletes served as his/her own control.

**Setting:** A high school in Pretoria.

**Participants:** The sample included adolescents (aged 13-18, male and female) that participated in school-related sport.

**Interventions:** Baseline values for the King-Devick- and the Cogstate test were obtained.

**Results: *King-Devick test:*** A statistically significant difference ( $p = 0.004$ ) between 2016 and 2017 baseline values with a low to medium effect size (Cohen's  $D: 0.38$ ) was found. Test-retest reliability was low (0.54) between 2016 and 2017 baseline values.

***Cogstate sport test:*** A statistically significant difference was observed for task one (psychomotor task) ( $p = 0.003$ ) and task two (visual attention task) ( $p = 0.005$ ). No statistically significant difference was seen for task three (visual learning) ( $p = 0.703$ ) and task four (working memory) ( $p = 0.149$ ). All effect sizes were low to poor (Cohen's  $D: -0.324$  to  $-0.044$ ). Low test-retest reliability (0.58 to 0.17) was found for each task between 2016 and 2017 baseline values.

**Conclusions:** Baselines should be conducted for each sporting season, to control for the low test-retest reliability scores. ***King-Devick test:*** The both sex and age are factors. ***Cogstate sport test:*** Sex does not seem to be a factor, only age.

**Key words:** Concussion; Baseline; Cogstate; King-Devick; Adolescents

**Clinical Relevance:** Impacts the management of concussion in adolescent athletes, highlighting the need for reliable baseline values to compensate for the varying cognitive function of the developing brain.

## 1. Introduction

The appropriate management and return to play decisions during sport-related concussion are currently one of the most widely debated issues in the sporting community. A concussive injury is highly individualized in nature, resulting in an array of signs and symptoms along with cognitive deficits making it significantly hard to diagnose and manage.<sup>[1,2,3]</sup>

Recurrent head injuries are connected to motor cortex dysfunction, early dementia and plaque build-up in the brain, also referred to as chronic traumatic encephalopathy (CTE).<sup>[4]</sup> Thus, the swift identification and appropriate athlete management is essential for the athlete's long-term health and athletic/sporting career.<sup>[4]</sup>

The need to understand the complex pathophysiology and evolving nature of a concussive injury gave rise to the development of new diagnostic and management tools.<sup>[4]</sup> Standardized tests, such as neuropsychological tests and oculomotor functioning tests, have ensured their role in the management of concussion within the clinical setting.<sup>[5]</sup>

The use of baseline values had been suggested as the best method for an unbiased diagnosis and a more accurate return to play decision.<sup>[6]</sup> The present literature favoring the implementation of baseline testing encourages the use of pre-season baseline testing prior to any contact play.<sup>[7,8,9,10]</sup>

The knowledge of a concussion history, the presence of mood disorders, learning- or attention deficits, and lastly a headache/migraine history can prove helpful in the diagnosis and management of a concussion.<sup>[7,11,12]</sup> Should the athlete sustain a concussive injury during his or her sporting season, his or her after-injury values can be compared to their baseline values for comparison.<sup>[6,13,14]</sup>

Research suggested that there may be a difference in the susceptibility and duration of recovery when it comes to sex and age.<sup>[12]</sup> Female athletes and adolescents were noted to be more prone to a protracted recovery course.<sup>[15]</sup> The immature brain has a more pronounced pathophysiological response, which leads to the conclusion that the youth are more susceptible to second impact syndrome.<sup>[7]</sup>

It's postulated that the biomechanical threshold for concussion in children and adolescents is lower than in a mature brain. This may be due to the increased plasticity during brain development.<sup>[7]</sup> Some of the main theories on why the developing brain is more susceptible to concussion are the incomplete myelination of brain tissue, and ossification of the cranium which results in less protection of the developing cortex.<sup>[9,10]</sup>

Males and females have also been found to perform differently on neuropsychological tests, especially in perceptual-motor speed and visuospatial tasks.<sup>[12]</sup> This is important to note and implies the need for individual baseline testing since females and males cannot be accurately assessed on the same norms.<sup>[15]</sup> However, literature available on youth athletes, especially research on sex and age groups, are limited thus norms are not properly established.<sup>[16]</sup>



Without proper diagnosis and management procedures in place a concussion may go unnoticed, which could lead to catastrophic outcomes like second impact syndrome or severe long-term cognitive impairments.<sup>[5,7,10]</sup>

## **2. Methods**

The main aim of this study was to investigate and report the difference in concussion baseline values from one sport season to the next. Baseline testing was done at the beginning of 2016 and then repeated a year later in 2017. These results were used to determine the test-retest reliability of a year old baseline test.

This study included the baseline values of the Cogstate sport test, a neuropsychological test, and the King-Devick (KD) test, an oculomotor test, often used in the assessment of concussion severity and the return to play decision making.

### **2.1 Participant selection criteria**

All participants were from a well-established high school, Hoërskool Waterkloof, in Pretoria, South Africa. All consenting students, both male and females, between the ages of 13 and 18 were included. The type of sport they participated in was not considered for this study. There were 108 participants for the KD test and 112 participants for the Cogstate sport test that successfully completed the baseline in both 2016 and 2017.

### **2.2 Cogstate Sport - Neuropsychological testing**

Neuropsychological testing is popular around the world and is described as the cornerstone of concussion management. In the current study only the computerized test, Cogstate Sport, will be discussed.<sup>[1,6,9,17,18]</sup>

The Cogstate program is a brief neuropsychological test battery specifically designed to measure cognitive function over repetitive intervals and to track any cognitive changes during these time intervals. Due to the fact that the test is computerized, the administration and scoring are automated and thus standardized.<sup>[7,13]</sup>

The test battery consists of four tasks, which takes approximately eight (8) to 15 min to complete.<sup>[1,6]</sup> Each task is presented as a card game, with a universal deck of playing cards as the stimulus set.<sup>[17]</sup> These tasks include simple stimuli requiring decisive responses within the set rules of each task.<sup>[17]</sup>

Task one is a detection task (psychomotor function), and task two is an identification task (visual attention). Both were measured by reaction time, measured in milliseconds (speed), which was then normalized using a logarithmic base transformation (Log 10).<sup>[6,17,19,20]</sup>

Task three is a one card learning task (visual learning) and task four is a one-back task (working memory). Both were measured by the proportion of the number of correct answers given, performance thus measures the accuracy. This was normalized using an arcsine square root transformation.<sup>[6,17,19,20]</sup>

The Cogstate sport test had shown to be sensitive to cognitive impairment in the sense that it successfully detects and tracks cognitive changes.<sup>[19,20]</sup> The test can be administered repeatedly without significant practice effects due to the randomization of stimuli.<sup>[19]</sup> For the Cogstate test, a low numerical value is considered bad while a higher numerical value is considered good. However, it is suggested that the Cogstate brief battery not be used in isolation but in conjunction with a more elaborate testing battery.<sup>[19,20]</sup>

## 2.3 Oculomotor test

The effects of a concussion include various aspects of impaired vision, impaired oculomotor speed (65-90% of concussed individuals) and difficulty with saccades.<sup>[20,21,22,23,24,25]</sup> Approximately 50% of the circuits in the brain are involved in vision thus rendering vision extremely susceptible to the effects of a concussion.<sup>[1,21,22,25]</sup>

The KD test is able to evaluate saccadic eye movement, attention, coordination, and language; all areas known to be affected by a concussive injury, especially during the acute phase.<sup>[1,16,22,24]</sup> Studies show that patients with a concussion had longer saccadic reaction times compared to non-concussed individuals.<sup>[22]</sup>

The KD test largely relies on baseline values, as normative data for adolescents are yet to be established in general.<sup>[23,24]</sup> Specific time frames for administering the KD test post-concussion has not been clearly defined but studies show that it is most effective within the first 72 hours post-injury, thus placing it in the side-line category of concussion management tools during the acute phase.<sup>[1,5,16]</sup>

Directly following the injury there is a complex ionic cascade taking place within the brain, during which cognitive dysfunction may manifest and signs and symptoms may appear.<sup>[22]</sup> Research suggests that the KD test should not be administered within the first 15 minutes following a concussive injury to avoid false negatives.<sup>[1,22]</sup> Fatigue may also be a confounding factor, thus a rest period is advised.<sup>[1,23]</sup>

The administration of the KD test is relatively simple and inexpensive.<sup>[21,24,26]</sup> The test itself takes between one to two minutes to conduct making it time effective.<sup>[16,21,22,23,25,27]</sup> Current research reports that a three-second deviation from baseline is still acceptable but that five seconds or more is indicative of a concussion, a significant drop in after injury times compared to baseline times was observed.<sup>[16,22,28]</sup>

The KD test requires participants to read a series of single digit numbers out loud from three test cards,<sup>[16,21,22,23,29]</sup> without using a finger or a pointer.<sup>[38]</sup> The numbers are read from left to right and top to bottom, the same as normal reading patterns.<sup>[22,23,29]</sup> The numbers are uniquely spaced for each card and increases in visual-spatial difficulty.<sup>[25]</sup>

Any immediate self-corrections are not counted as errors, those not corrected requires the participant to re-start the test.<sup>[22,23,29]</sup> A maximum of three attempts per card is permitted before continuing with the next card.<sup>[22,23,29]</sup> In the end, the sum of the time taken for all three cards is recorded along with a number of errors. The fastest time without errors is then used as the baseline.<sup>[16,22,23,29]</sup>

### **3. Ethical Considerations**

Written consent was obtained from each participant's legal guardian for their participation and for the use of their baseline data for this study. The participants took part out of their own free will and the data used was kept anonymous. Both baseline test were non-invasive and no harm or discomfort where to be expected.

#### 4. Results

The raw data from this study was captured in Excel 2013 and converted into a STATA 14 format before detailed analysis. The **first objective** was to determine and quantify changes in baseline values for the KD test (Table 1.1) and Cogstate sport test (Table 1.2) for all the involved participants measured at the start of the 2016 and 2017 sports season. The descriptive statistics mean, median, standard deviation and inter-quartile range were used to describe the test scores from the KD test (Table 1.1) and Cogstate test (Table 1.2).

The **second objective** was to determine the significance of the difference between the 2016 and 2017 baseline values, including test-retest reliability in both the KD test (Table 1.1) and Cogstate Sport tests (Table 1.2).

The **T-test** was used for the Cogstate sport test (Table 1.2) to determine if there were any statistically significant differences between baseline values from 2016 to 2017 for all four tasks of the Cogstate sport test. The **Kruskal-Wallis non-parametric** test was used for the KD test (Table 1.1), as an alternative to the T-tests because there was an outlier which it could accommodate for.

For both the KD test (Table 1.1) and the Cogstate sport test (Table 1.2) the **effect sizes (Cohen's D)** were calculated. This score is used to indicate the standardised difference between two groups and helps to evaluate the differences found. The values can be interpreted from a clinical perspective as follow; 0.2 or less = Small; between 0.3 and 0.5 = Medium; between 0.6 and 0.8 = Large; and 0.9+ = Very large.<sup>[41]</sup>

The **interclass correlation coefficient (ICC)** was used to determine the test re-test reliability of baseline values for the KD test (Table 1.1) and the Cogstate sport test

(Table 1.2) from two consecutive years. The values can be interpreted from a clinical perspective as follow; less than 0.40 = poor; between 0.40 and 0.59 = low; between 0.60 and 0.69 = marginal; 0.7 and 0.79 = adequate; between 0.8 and 0.89 = good; and 0.9 and more = excellent.<sup>[4]</sup>

The **third objective** was to determine if differences in baseline values with respect to sex and age observed in objective one were statistically significant for the KD test (Table 1.1) and Cogstate sport test (Table 1.2).

The **Kruskal-Wallis non-parametric** test was used for the KD test (Table 1.1) and the Cogstate sport test (Table 1.2), as an alternative to the T-tests because sample sizes within combinations of sex and year of birth were too small. The **Two-way ANOVA** was used to determine if there were any statistically significant differences between baseline values from 2016 to 2017 for all four tasks of the Cogstate sport test (Table 1.2).

The null hypothesis, for both the KD test (Table 1.1) and the Cogstate sport test (Table 1.2), would be that there is no significant difference between to specified variables. If the significance value is less than 0.05, the null hypothesis can be rejected. The only exception was the Cogstate sport test (Table 1.2), in the statistical analysis for objective two. The Bonferroni correction was used, and the p-value was adjusted to 0.0125 to accommodate for the multiple testing of all four tasks.

## **5. Discussion**

### **5.1 The King-Devick test**

For the KD test a statistically significant difference ( $p = 0.0001$ ) between baseline values from 2016 and 2017 was observed, although a small effect size ( $D: -0.376$ )

was reported. The 3.02s improvement observed between 2016 to 2017 baseline values in the current study suggest that there is a potential for misdiagnoses when using a year old baseline, with the five-second deviation as a reference.<sup>[16,22,28]</sup>

The test-retest reliability between 2016 and 2017 baseline values was found to be low (0.542) in the current study. Test-retest reliability seems to be negatively affected by the amount of time passed, rendering the test-retest reliability below clinically acceptable values (0.6) after a single year.<sup>[30]</sup> These results confirm that each new sporting season warrants a new pre-season baseline.<sup>[13]</sup>

The statistically significant difference seen in the total participant group ( $p = 0.004$ ) is between sexes and not between participants of the same sex. Current literature supports this finding by suggesting individual baseline testing should be conducted since females and males cannot be accurately assessed on the same norms.<sup>[15,27]</sup>

There was no statistically significant difference for KD baseline values from one year to the next for the three oldest age groups. However, a statistically significant difference ( $p = 0.044$ ) was found between baseline values after one year for those born in 2002 (age 13 to 15), the youngest age group.

The current study concludes that there is a difference in cognitive ability between the two sexes and the cognitive development is more prominent in the younger spectrum of adolescence.<sup>[2,14,27]</sup>

## **5.2 Cogstate Sport test**

The Cogstate sport test results showed a statistically significant difference between baseline values from 2016 to 2017 for task one ( $p = 0.003$ ) and task two ( $p = 0.005$ ). However, no statistically significant difference was reported for task three ( $p = 0.703$ )

and task four ( $p = 0.149$ ) between baseline values from 2016 to 2017. A small effect size ( $D: -0.044 - 0.324$ ) was found for the differences between baseline values from one year to the next for each of the four tasks.

No statistically significant difference ( $p = 0.326$  to  $0.064$ ) was found between 2016 to 2017 baseline values amongst participants within the same age groups. However, a statistically significant difference ( $p = 0.001$ ) was found between 2016 and 2017 baseline values between the different age groups. This suggests that athletes from the same age group perform similarly but that there is a difference between different age groups.

A statistically significant difference between 2016 and 2017 baseline values was found amongst males participants ( $p = 0.006$ ) and amongst females participants ( $p = 0.003$ ). However, there was no statistically significant difference ( $p = 0.262$ ) found between the two sexes.

The conclusion is that sex may not be the major factor but rather age in the changes observed in baseline performance for the Cogstate test. It had previously been found that males and females perform differently on neuropsychological tests.<sup>[12]</sup> However, the mean values and differences observed in the current study, between the sexes, showed similar trends and values.

A difference in task performance between age groups was noted in the current study. Each task tests a different cognitive domain. It might be worth considering the 'neurological pruning', a period of dynamic structural changes within the neurological structure of the brain during the adolescent period.<sup>[2]</sup> More insight might aid in the diagnosis of a concussion and the management thereof if it is known which cognitive domain at a certain age might be more affected by a concussive injury.



The low to poor test-retest reliability shown between 2016 and 2017 baseline values for the current study are below clinical standards (0.6), suggesting that a year old baseline might not be the best measure for proper concussion management. The low test-retest reliability in the current study could be attributed to the time elapsed between testing sessions. A study done by Bruce et al. (2016) found that test-retest reliability seemed to decline with time, but that regular baseline testing may have the potential to improve the test-retest reliability.<sup>[30]</sup>

A plausible reason for the observed variability in test-retest reliability scores, observed with elapsed time, could be the significant structural changes seen in the adolescent brain, representing the natural growth and development that takes place during adolescence.<sup>[2,14,27,28]</sup>

## **6. Limits**

The literature suggests that a participant with a concussion history or that had sustained a previous concussive injury tend to perform worse than their non-concussed peers in a neurophysiological test.<sup>[16,17,28]</sup> For this study, the individual concussion history was not documented and therefore could not be considered.

Another limitation that was noted for this study was the potential of learning effects for the KD test. Signs of a learning effect between the first and second test trial in certain studies have been noted.<sup>[22]</sup> In order to help counter this learning effect, two sets of test cards have been developed to be used interchangeably.<sup>[22]</sup> This study did not control for the potential learning effect, the same set of test cards were used for 2017 as was used in 2016.

## 7. Conclusions

Given the variability of the natural maturation process, and that not all chronological maturation follow the same biological maturation, it can be suggested that an individualized baseline would ensure a more accurate diagnosis than using normative values.<sup>[13,28]</sup> If we were to use the norm the individual with the minimum score would be misdiagnosed and the individual with the higher score would be prematurely sent back to play.<sup>[13,30]</sup>

The current study would suggest that timing and planning plays an important role in the holistic approach to effective concussion management, and would propose that periodization is considered in future research and concussion initiatives. Although schools and sporting codes vary in their pre-season and in-season duration and time of year, it still proves to be a variable within the school's control.

A study done by Whitford et al. (2007) recorded significant structural changes within the brain during the adolescent period, indicating that changes and different levels of performance in cognitive function ought to be expected from one age group to the next.<sup>[31]</sup> Baseline testing is suggested to be administered regularly, not just to ensure test-retest reliability, due to time, but to accommodate for these neurological changes that occur with age, that seemingly affect cognitive test performance.<sup>[14,27]</sup>

The athlete's concussion profile, history, and available baseline data, should grow along with the maturing athlete to ensure continued safe play and decision making in his or her athletic career.

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In Table 1.1 the summarized trends and interpretation thereof are shown for each objective for the KD test.

*Table 1.1 – A summary of all the KD test results for each objective.*

Objective one - to determine and quantify changes in baseline values for the KD test for all the involved participants measured at the start of the 2016 and 2017 sports season.			
Variable	Trend	Direction	Interpretation
<i>Males, females and the total group.</i>	Yes	Decrease in mean value	Improvement by all participants
<i>All the different age groups.</i>	Yes	Decrease in mean value	Youngest groups showed biggest improvement
<i>Different age groups in the female participant group.</i>	Yes	Decrease in mean value	Each age group improved, the youngest improved most
<i>Different age groups in the male participant group.</i>	Yes	Decrease in mean value	Each age group improved, the youngest improved most
Objective two - to determine the significance of the difference between the 2016 and 2017 baseline values, including test-retest reliability of the KD test.			
<i>Kruskal-Wallis non-parametric test results for the total participant group.</i>	Yes (p = 0.0001)		Statistically significant difference found
<i>Effect sizes for the total participant group.</i>	Cohen's D:0.38		Small to medium effect
<i>The ICC value between 2016 and 2017 baseline scores for the total participant group.</i>	0.54		Low test re-test reliability
Objective three - to determine if differences in baseline values with respect to sex and age observed in objective one were statistically significant for the KD test.			
<i>Kruskal-Wallis non-parametric test results for the different age groups, male- and female participant groups, and for the total group as well.</i>	Born 1999 (p = 0.63) Born in 2000 (p = 0.75) Born in 2001 (p = 0.168) Born in 2002 (p = 0.043) Males (p = 0.29) Females (p = 0.74)	Decrease in mean value	There was no statistically significant difference between males and females or for the three oldest age groups. There was a statistically significant difference for the youngest age group.

In Table 1.2 the summarized trends and interpretation thereof are shown for each objective for the Cogstate sport test.

*Table 1.2 – A summary of all the Cogstate sport test results for each objective.*

Objective one - to determine and quantify changes in baseline values for the Cogstate sport test for all the involved participants measured at the start of the 2016 and 2017 sports season.			
Variable	Trend	Direction	Interpretation
<i>Males, females and the total group.</i>	Yes	10/12 decreased	All performed worst
<i>All the different age groups.</i>	Unclear	7/16 decreased	The two youngest age groups performed worst.
<i>Different age groups in the female participant group.</i>	Unclear	11/16 decreased	The two youngest age groups performed worst.
<i>Different age groups in the male participant group.</i>	Unclear	7/16 decreased	The two youngest age groups performed worst.
Objective two - to determine the significance of the difference between the 2016 and 2017 baseline values, including test-retest reliability in the Cogstate sport test.			
<i>T-test results for each task in the Cogstate sport test for the total participant group.</i>	Task one (p = 0.003) Task two (p = 0.005) Task three (p = 0.703) Task four (p = 0.149)		Task one and two showed a statistically significant difference, task three and four did not.
<i>Effect sizes, Cohen's D (D) values for the total group and all four tasks.</i>	Combined (D: 0.244) Task one (D: 0.324) Task two (D: 0.270) Task three (D: -0.044) Task four (D: 0.126)		Small to medium effect sizes
<i>The ICC value for the total participant group and all four tasks</i>	Combined (0.53) Task one (0.31) Task two (0.5) Task three (0.17) Task four (0.58)		Poor to low test re-test reliability
Objective three - to determine if differences in baseline values with respect to sex and age observed in objective one were statistically significant for the Cogstate sport test.			
<i>Kruskal-Wallis non-parametric test results for the different age groups.</i>	Born 1999 (p = 0.064) Born in 2000 (p = 0.205) Born in 2001 (p = 0.248) Born in 2002 (p = 0.326)		No statistically significant difference found for any of the age groups
<i>Two-way ANOVA test results for the combined Cogstate sport baseline values between 2016 and 2017.</i>	Within male group: (p = 0.0068) Within female group: (p = 0.003) Between sexes: (p = 0.262) Between age groups: (p = 0.245)		No statistically significant difference between sexes or an interaction between sex and age. Age does show a statistically significant difference between age groups with in a sex.