Analysis of baseline testing for improving the detection, education, and management of concussion

By

Gregory Sammons

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Abstract

Intro: Concussion is becoming increasingly important within professional sports and has attracted significant formal and social media attention. The exact neuropathological processes in concussion have yet to be clarified and the wide variety of signs and symptoms of concussion are not widely appreciated.

Aims: To ascertain whether baseline testing in Professional Cricket aids or alters the diagnosis/management of concussion, and whether it contributes to the knowledge and awareness of concussion among the cricketers. A secondary aim was to ascertain if there was a difference in awareness between cricketers and other contact sports.

Method: A pilot study involved 57 players from 4 professional County Cricket Clubs and the main multicentre study involved 655 players from 17 professional County Cricket Clubs. Comparison groups for the awareness of concussion involved 61 Rugby Union players and 64 Rugby League players.

Results: There was an increase in reported concussions in County Cricket, but these increases were not statistically significant.

There was an increase in levels of knowledge about concussion in professional cricket, but these improvements were not statistically significant.

There were no significant differences in awareness of concussion between professional cricketers and professional Rugby Union and Rugby League Players.

Conclusions: The study demonstrated an improvement in the diagnosis of concussion and in the knowledge of the signs and symptoms of concussion over the 3yr study period. It is highly likely that future continued work will be able to demonstrate significance in improving concussion management and the associated sequelae.

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Contents

FIGURES

TABLES

1.0 Introduction

Concussion can be defined as a disturbance of an individual's neurological abilities. From an impact on the brain via external forces it leads to inhibited functionality and impaired homeostasis.

Concussion is prevalent throughout the world of sport but has notably been seen throughout history to occur mainly in contact sports, such as Rugby and American Football. Due to the high levels of contact, the interest in investigating the high impact collisions on athletes both during training and game time in these sports, has led to the uncovering of the associated linkage to head injuries. However, that is not to say that in non-contact sports such as cricket and football that concussion is not prevalent - within the professional game and all other levels. Due to the limited research within the high-profile area of concussion, it could be silently impacting sports in many ways, therefore research across all sports should be occurring to enable better player welfare. By enabling key players to recover quicker after a concussive episode, reducing time loss injuries and ensuring higher quality return to play processes, disruptions to the performance squad are reduced.

Baseline testing is described as the documentation of specific tests that are designed to create a 'baseline' score on which an individual's performance outcomes can be compared if required. The baseline score is a standard and point of reference on which to be referred, both for medical and performance purposes.

Baseline testing is used throughout multiple sports to track and monitor an athlete's progression or regression over time. For example, when strength testing an athlete, an improvement may be seen from one point of the season to another, this can be used for a coach to recognise if an intervention is needed.

In this study, baseline testing is used as the measuring standard on which to aid the detection and management of concussion in professional cricket players, and to assess its current effectiveness and appropriate suggestion for its use in the wider field of professional sports in the future.

The two main elements of this project and research question are both education and clinical, with both components carrying the same importance to the outcome.

The baseline testing in this study, which uses professional cricket players as the athletes, aims to aid the diagnosis and management of concussion, and to see whether it contributes to the knowledge and understanding of concussion among the athletes observed. A secondary aim was to ascertain if there was a difference in this awareness, between cricketers and other contact sports.

The motivation for this project comes from my own personal experience playing professional sports for years and suffering concussive episodes first-hand, experiencing the management of these episodes, and returning to play protocols within the then current advice. With teammates retiring early due to concussion and their lives being impacted after these episodes, it was clear it was an injury that was not clearly understood or managed appropriately, and I wanted to further understand the reasoning behind this.

Furthering my career working within professional sport in a Strength and Conditioning capacity and running performance teams, I again experienced concussive episodes with athletes on a first-hand basis. Therefore, when given the opportunity to participate in this research, I knew I wanted to complete a PhD in Sports Medicine and evaluate concussion detection, management, and education in particular.

It is extremely difficult to determine whether someone's neurological function is disturbed, unless it is grossly altered, without baseline testing. This is due to every individual having such a wide range of neurological ability. One of the aims of this study is to bridge this gap.

Concussion in Cricket has been actively under review since the tragic loss of Phillip Hughes. The Australian International Cricket player passed away in 2014 after being struck just beneath the left ear by a "bouncer" cricket ball. He was rushed into hospital in Sydney where he was unconscious for two days before sadly passing away. As a result, concussion is also becoming increasingly recognised throughout many sports such as American Football, Rugby Union, Football (Soccer) and Cricket (Colello et al., 2018; Gallo et al., 2017; Orchard et al., 2016 and Williams, 2010).

The specific research question became apparent after the researcher and Doctor Douglas Hammond were working together and had many discussions about player welfare in professional sport and discussed practices, we thought could impact positively on this. With the death of Philip Hughes becoming a huge media driver for research and change in cricket. Discussions between the research and the Chief Medical Officer at the English Cricket Board, Professor Nick Pearce, highlighted that a better understanding of concussion in cricket is urgently needed.

The absolute definition of concussion has evolved over time and is often contested. However, it can be defined as ‘a temporary disruption in normal brain function after a mechanical impact or transmission of force through cerebral tissue’ (Budinger, 2016). It has also been referred to by Budinger, (2016) as a mild traumatic brain injury (mTBI). Concussion is often caused by an external force causing rapid impairment of neurological functions which in turn can cause normal brain function to be disturbed. By definition, there is no external structural injury. However, the behavioural changes of concussion have been noted throughout history. As early as 1848 a neuroscientist’s case records demonstrated the relationship between head trauma and behavioural changes when a rail worker, Phineas Gage, suffered a serious traumatic brain injury and somehow recovered. However, it was noted that he seemed a different person (Harlow, 1848).

More recently, events in the Middle East have seen an increase in brain trauma to soldiers caused by improvised explosive devices, (IEDs) with autopsies showing brain tissue injuries to be like veteran boxers. Furthermore, recording of progressive dysfunctional behaviours including depression and suicidal thoughts among elite American Football players, has been shown to be like soldiers who survived blasts, and boxers with multiple concussions. History confirms that concussion does not just occur within the sporting arena, as many physicians showed concern for soldiers’ psychiatric disorders after shell blasts throughout World War I (1914-1918) and even earlier in the American Civil War in 1864 (Myers, 1915 and Mitchell, 1941).

Postmortem studies show cerebral traumatic encephalopathy (CTE) within American Football players (McKee *et al.,* 2009; Omalu *et al.,* 2006). Even though we have recognised TBI for at least 300 years, and with the clinical signs and symptoms recognised over 100 years ago, our understanding of the pathophysiology of the injury is still very limited. Most recently between 2006-2016 it has been shown that an increase in concussive episodes has been recorded within elite sports, with the largest increase seen in 2015-16. This may be due to a previous lack of education, but also an increase of interest shown by the media and elite sports organisers, such as American football, towards the longer-term risk to athletes (Orchard et al., 2016).

The National Health Service (NHS) provides care for serious injuries every day within the United Kingdom. This is also seen across the globe. A review paper from Switzerland showed that, out of a total of 750 patients with maxillofacial injuries, only 12% were sports related with 27% from skiing and snowboarding, and 22% from team contact sports. However, this is all secondary to major motor vehicle trauma such as motorbike accidents that makes up the rest of the 88% (Exadaktylos et al., 2004).

Intracranial haemorrhages are also common injuries, with 13.8% of patients having sports-related maxillofacial fractures (Mourouzis et al., 2005). Patients with multiple maxillofacial fractures account for between 3.6% - 7.2% of all traumatic injuries (Carrol et al., 1995 and Tanaka et al., 1996). Early recognition of any injury by the NHS is key to obtaining the correct outcome for the patients. Eliyahu et al., (2016) affirm that 85% of all brain injuries occur from concussion or mTBI, and consequently it is important that all medical teams have a greater understanding of all the signs, symptoms, and probable outcomes of any concussive episode (Rhazes, 1497).

A frequent misconception is that an individual must be knocked on the head and ‘lose consciousness’ for a concussion and signs and symptoms to occur. In their study, Ferry and

DeCastro, (2020) showed that only 10% of patients lost consciousness. However, a concussion can result from an impact or injuries involving other areas of the body (Cannon, 2001) and damage from the transmission of kinetic energy from impact to remote body organs have caused concussion (Krajas, 2009 and Sperry, 1993).

Traditionally, Medical Doctors have carried the burden of diagnosing concussion within the public sector for many years. However, due to a heightened concern in the media, sporting organisations have started to ramp up awareness campaigns to educate parents. Due to a lack of research and specific management channels, the NHS could become overwhelmed with concussed patients if there was a spike in cases with no long-term management strategy in place (Ahmed and Weiler 2016). Potentially, adopting a different approach and using the knowledge gained within the sporting world may be something to review in the future whilst developing protocols within the NHS. Campaigns aimed around trying to educate parents and physicians across the UK and throughout the sporting world would be useful. With the NHS Emergency Departments still incurring most national concussion cases, it indicates further research into increasing the knowledge of signs and symptoms of concussion may be useful for both parents and physicians.

A concussion does not just occur within a certain type of a person. It does not have the ability to pick its victim, it is simply that the traumatic incident causes the concussion to occur. Recognising TBI as the leading cause of disability or death to children within the United States, confirms that concussion can really affect all ages (Budinger, 2014). The Centres for Disease Control and Prevention (CDC) concurrently state that the two most vulnerable ages for sustaining a TBI are 0-4 years and 15-19 years old with causes ranging from vehicle crashes and sporting injury to physical abuse cases (Budinger, 2014). Furthermore, adolescents play more regular sport through school classes, weekend matches and after school clubs increasing the risk of a potential concussion, despite many people saying "you heal faster when you are younger". Kirkwell et al., (2014) showed that adolescents that play contact sports such as Rugby Union and Rugby league are at an increased risk of sustaining a concussion. Rugby Union and Rugby League are both major sports within the UK school curriculum along with Cricket and Football (Soccer). The research project by Kirkwood et al., (2014) reviewed 25 studies of concussion involving adolescents with data showing incidences of within match concussion ranging from 0.2 to 6.9 concussions per 1000 hours of rugby played for rugby union and 4.6 and 14.7 concussions per 1000 hours of rugby played for rugby league, equivalent to a probability of between 0.3% and 11.4% for rugby union and of 7.7% and 22.7% for rugby league. These results show significant risk to adolescents and children and the need for the NHS and schools to set up a review process to gain further knowledge and understanding. However, as previously stated by Ahmed and Weiler., (2016) this isn't possible due to other factors such as staffing, money and other resources. So, the question remains, how do we move the process forward? A deeper understanding is also needed within non-contact sports such as professional cricket, to determine the varying ways concussion can occur within other sports and to add value to this topical area.

Intracranial haemorrhages are also common injuries within the NHS, with 13.8% of patients having sports-related maxillofacial fractures (Mourouzis et al., 2005) and patients with multiple maxillofacial fractures account for between 3.6% - 7.2% of all traumatic injuries (Carrol et al., 1995 and Tanaka et al., 1996). Early recognition of any injury by the NHS is key to obtaining the correct outcome for the patient. Eliyahu et al., (2016) affirm that 85% of all brain injuries occur from concussion or mTBI, and consequently, it is important that all medical teams have a greater understanding of all the signs, symptoms, and probable outcomes of any concussive episode. However, to start, an understanding into the levels of knowledge that medical practitioners have would be beneficial to show a reflection of what greater knowledge would look like, compared to a maximum, mean and low score within their practitioner's group.

Within this study, the role of the researcher within the team will be to lead the entire research study, from the collection of data and analysis to the integration and training on concussion baseline testing throughout the entire ECB and the 18 county cricket teams. Whilst also aligning and driving the education in and around the topical area for players and staff, the researcher will drive the intervention over a 3-year period in the hope to see a difference made within professional sport and for future years to come.

In the following chapter the levels of knowledge and understanding of concussion will be discussed within the realm of professional cricket, using baseline testing to drive the process and enable individual diagnosis and better advice for the injured athletes. The researcher will discuss and review appropriate literature from both past and present publications, whilst critically analysing the effectiveness of past work to enable a true reflection of past literature and methods. The researcher will investigate current concussive episodes and the management, methods, and knowledge of concussion whilst discussing and advising the best methods used within baseline testing protocols for future evaluation and future research.

The results from a pilot study conducted to investigate and discuss if a full roll out across all counties was viable and necessary. This will include a discussion of this multicentred study to gain a true understanding and insight into individual baseline testing, knowledge and understanding of concussion and if further education and advice is needed within professional sports. Finally, the risk within professional will be discussed and relevant finding evaluated whether concussion is a risk within professional cricket, discuss relevant findings and evaluate and suggest future research.

1.1 Elements of originality

The research will answer the research hypothesis through validation and analysis of the large amount of data collected. Models will be developed from the MPhil stage and adapted where necessary. To validate and maintain validity the research teams visiting the different County Cricket Clubs throughout England will be trained and supported by the lead researcher. To my knowledge no previous research has ever completed a simultaneous baseline testing project of professional cricket players. This will provide opportunities for future research which will help to answer previously unanswered questions.

The research will also provide:

1. Confirmation about the levels of education about and understanding of concussion within a large group of Professional Cricketers.

2. Evidence about the mental toughness of Professional Cricketers, allowing comparison with available data sets in other sports.

3. A refined insight into the levels and understanding of concussion in Professional Cricketers, which could potentially influence the management of a concussive episode involving them.

4. Evidence whether baseline testing should become the norm and thus facilitate improved athlete care and infrastructure change within the sporting environment.

The baseline testing in this PhD can be done by non-medically qualified personnel and it is our aspiration that in the future such tests should not be confined to elite athletes.

Aims and Objectives

The work within this thesis will attempt to answer the following research questions:

1. Does baseline testing aid the diagnosis and/or alter the management of concussion for Professional Cricketers?

2. Does baseline testing facilitate and contribute to the knowledge and awareness of concussion among Professional Cricketers?

Aims

- To determine whether the use of non-invasive tests aids or alters the diagnosis or management of a concussive episode in professional cricket

- To quantify the number of maxillofacial injuries, concussive episodes and helmet strikes in Professional Cricketers over a specific period of time

- To ascertain whether Professional Cricketers have an understanding of concussion prior to baseline testing

- To investigate whether baseline testing improves player understanding of concussion

- To determine whether baseline testing improves players understanding of concussion between non-contact and contact professional sports

- To investigate whether there is a relationship between Professional Cricketers' mental toughness and their rehabilitation from concussion

Objectives

To achieve these aims the following objectives will be identified:

- To conduct a survey of Professional Cricketers playing county cricket in England and to collect information on their playing history and details of any sport-related concussive episodes

- To establish cricketer's knowledge and understanding of concussion through a quantitative research analysis of questionnaires

- To carry out baseline medical screening and establish baseline scores for a range of physical and psychological ability tests

- To correlate the experimental data producing a coherent analysis of all data sets allowing comparison of baseline scores, knowledge and understanding questionnaires and mental toughness questionnaires to find differences among test results and players characteristics.

- To perform a retrospective validation of the data collection and baseline testing protocols to enable rigorous testing of the model, therefore testing the hypothesis 'Does baseline testing aid in the education of concussion within Professional Cricketers?' At the same time making use of appropriate statistical data from other sports such as Rugby Union and Rugby League as a comparison

The following chapters will cover an in-depth literature review of concussion from past and present research with a critical analysis of the studies and research conducted to demonstrate the gap in the current findings. The first part of the literature review will dive into the biomechanics of concussion, MRI scanning for concussion, the signs and symptoms of concussion and concussion within the NHS. The following parts will move to investigating whether concussion is predictable and recoverable whilst investigating if injuries within sports benefit from protective equipment. A review of tests used or validated through other research will be determined, and finally an understanding of the level of knowledge and awareness of concussion as a topical area will be discussed. These varying topics will be key to drive forward the understanding of the levels of knowledge around concussion within professional cricket. It will add to literature regarding the use of baseline testing throughout professional sports whilst validating the use of each test by piloting the methods. The following chapters will investigate a pilot study to allow a better understanding if baseline testing is needed in professional cricket and the context of concussion within the sport. The protective equipment in professional cricket may reduce maxillofacial injuries and reduce concussive episodes, therefore an investigation into the rate of helmet strikes, maxillofacial injuries and concussion is warranted. The need to dive deeper into the area of concussion within professional cricket will be explored to gain a true reflection through a multicentred study, the current levels of knowledge and understanding of concussion will be investigated over a 3-year period and discussed to see if they improve. The use of baseline testing may also be a cost effective and easily non-invasive method in understanding the issues in other sports and in the public domain therefore, future research and elements of the findings will be spoken in and around. Conclusions will be made to whether baseline testing can improve the detection, education, and management of concussion within professional cricket.

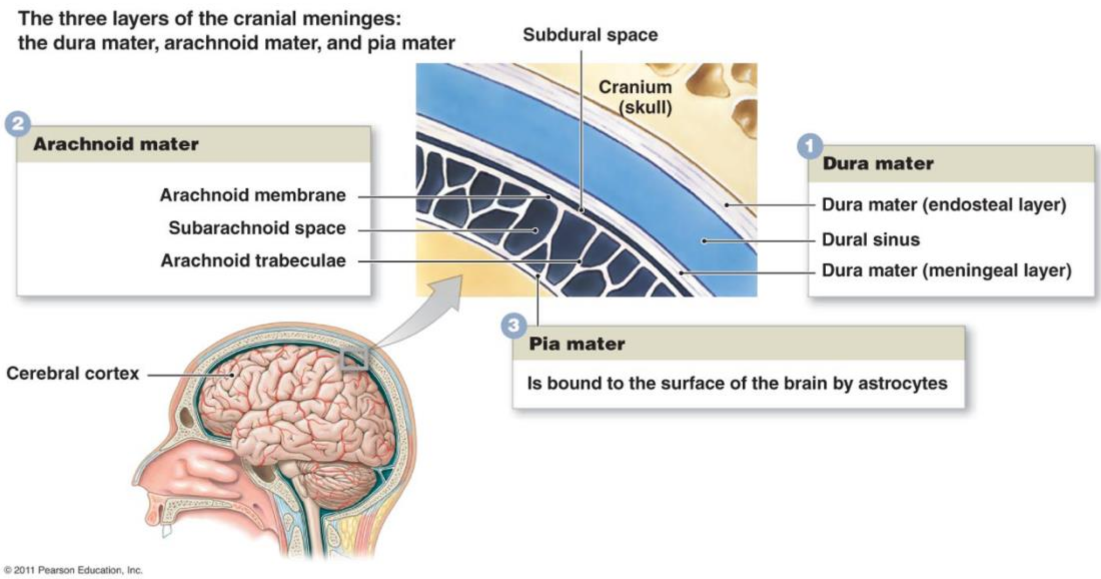
Chapter 2. Literature Review

This literature review relates to the clinical and laboratory diagnosis of concussion and its recovery, with particular emphasis on sports related concussive injuries. This literature review will shape the basis for this research project and look to identify the gaps within research and its methods to enable this study to demonstrate its value.

2.1 Mechanisms of Brain Trauma

The brain is encased within its own hard shell (the Cranium) almost like a helmet. The function of these layers is to protect the brain and spinal cord from mechanical injury, provide blood supply to the skull and to the hemispheres, and to provide the space for the flow of cerebrospinal fluid (Sameul, 2020). See Figure 1.1.

Figure 1.1. The structure of the cranial meninges and the relationship of the brain tissue to the skull (cranium)



Thus, the brain is encased within a very rigid bony case and the mode of deformation of the brain from a force such a blow to the head or a fall, is that the brain tissue is compressed in one direction and stretched in another (Budinger, 2014). The inflammatory response following the incident of a traumatic brain injury (TBI) is defined by the release of pro- and anti-inflammatory mediators such as cytokines, arachidonic acid metabolites and soluble adhesion molecules, interleukin-6 (IL-6), IL-12 and Malone dialdehyde (MDA) (Arand et al., 2001). TBI is the most common cause of death to people under age 40 with a head injury (Baxter and Wilson, 2012).

TBI is not a single disease but several pathologies that all occur in isolation, such as an extradural haematoma, often seen with skull fractures when an accumulation of blood forms between the inner surface of the skull and the outer layer of the dura (Baxter, 2012). A TBI can also co-exist with subdural haematomas and axonal injuries and are often caused through road traffic incidents (RTI) (Sahuquillo- Barris et al., 1988).

There are varying degrees of brain injury, and this depends on the level of injury sustained. TBI has shown to affect a large part of a human’s brain. Half of the brain circuits are devoted to vision and eye movement, and they have been shown to be a good objective biomarker of TBI (Ditta, et al., 2019). However, the diagnosis of a TBI can be challenging. Although magnetic resonance imaging (MRI) and computer tomography (CT) scanning are helpful tools to aid diagnosis of TBI, the far greater challenge through research is to improve the diagnosis and management of TBI (O'Keeffe et al., 2019).

It is thought that cellular and subcellular levels within a TBI should be the primary focal point for research. Farkas and Povlishock, (2007) suggest that cell death cascades within non-contusional cascades should not be overlooked and could be triggered by the diffuse mechanical forces in an injury. The traditional death cascades involve the activation of cysteine protease with the non- traditional pathways involving lysosomal dependent release of hydrolytic enzymes both ensuring neuronal death. Recent literature suggests that our once simplistic approach to understanding TBI doesn't work, and a further deeper understanding is needed from future research with good quality data (Brian, 2013).

TBI has clinical complexity around the vast subject of both the invisible and visible loss of societal productivity. This indicates the urgency for better knowledge and understanding of brain injuries. The complexity of TBI, sadly, results in a lot of controversies (Moore et al., 2019) and furthermore, no clinical trials for novel treatment of severe TBI have been successful to date (making the need for non-invasive mass testing protocols to potentially be the best way of gaining great knowledge and understanding of TBI.

2.2 Biomechanics of a Concussion

Concussive episodes have been missed over the past decades due to a lack of education and understanding of the biomechanics of such episodes. Between 2006 and 2016 Orchard et al., (2016) suggested there had been an increase in concussions with the largest increase seen between 2015-2016, which might suggest that an improved understanding had occurred over the period of study.

Biomechanics can give an interesting insight into what happens when a concussion transpires. There are multiple different interrelationships among the forces produced during a head impact or head and neck movements (Margulies, 2016). With each TBI varying, the biological response of the body may be delayed or immediate. Margulies, (2016) suggested that two subcategories can best describe the potential areas an TBI can occur: structural (torn vessels and axons) and functional (changes in blood flow or neurological status) with these also differing with maturation.

Biomechanical investigators typically use a variety of approaches prospectively and retrospectively when investigating concussion: (Camarillo et al., 2013; Crisco et al., 2010; Daniel et al., 2012; Rowson et al., 2009 and 2012).

- a direct measure of loading conditions and responses in humans, animals, and anthropomorphic surrogates (test dummies)

- visualization of tissue responses to prescribed loads to characterize the response of complex geometrics or composite structures

- mechanical property testing of individual components to identify changes with age

- computational models to predict how tissues will deform during impact or rapid head rotation

- identification of the time course of the cell or tissue response to specified deformations to define thresholds associated with various types of injuries

Concussions are diagnosed by symptoms and largely rely on the patient's willingness to report these to a physician, thus potentially making this data slightly less reliable (Margulies, 2016). Willingness however might not be the issue, as how can a person diagnose themselves with a concussion if they do not understand what a concussive episode and its signs and symptoms are, and with its varying severity of each symptom, it makes it very hard to distinguish between a normal headache and a headache due to concussion.

To obtain objective measures of biomechanical thresholds of concussion, varying types of sensors have been used within mouthguards, helmets, and patches. However, these sensors have also been seen to produce limited data on rotational head movements (Margulies, 2016). Sensors have also been used on headbands, skullcaps and directly on a patient’s skull to see if the sensors can become more reliable (Bartsch et al., 2014; Hernandez et al., 2015 and King et al., 2015). Furthermore, placing something externally onto the skull or within the mouth maybe too far removed for a reliable measure of a true brain injury occurrence. Recent studies show that quantified errors in risk curves are associated with significant sensor inaccuracy (Allison et al., 2014, 2015). Previously, injury risk curves have been the most common approach when quantifying a link between biomechanical input and concussion (Pellman et al., 2003). It is estimated that sensor inaccuracy may result in 53 per cent underreporting of concussions (Elliott et al., 2015).

Whilst referring to the most recent studies and taking into considerations the inaccuracies and limitations they bring; the aims and objectives of this study will be to establish reliable and effective methods for detection and management of concussion, whilst educating professional athletes and medical professionals alike and providing them with effective procedures to implement. The thread to tie all of this study together will be the element of education, for all parties addressed throughout the study.

Using varying baseline testing methods will be a key factor to encompass the different parts of the brain's function a concussive episode can affect. The different tests used will assess the different neurological output functions. Screening athletes on an individual basis will also allow for RTP/RTT processes to change and to be more focused on player wellbeing, improve care, and provide a more in-depth understanding around concussive episodes. I would also hope that the education around the topical area will improve significantly once baseline testing is administered and detection and management are a constant practice.

2.3 Signs and Symptomology of Concussion

Concussion is a complex neuro-metabolic condition and diagnosis relies on the assessment of patient cognitive function, symptoms, and motor function. However, there is not one sole diagnostic test that is conclusive making concussion very hard to diagnose (McCrory et al., 2013). The Zurich 2012 Concussion Consensus (McCrory et al., 2013) states that post-concussion symptoms fall under 5 categories: Somatic (headache, nausea, visual problems, balance problems dizziness and sensitivity to light and noise); Emotional (more emotional than normal, crying); Cognitive (trouble concentrating and remembering, 'foggy' sensation); Physical symptoms (amnesia); and Sleep disturbance (trouble sleeping or drowsiness). With the symptoms of a concussive episode being so variable it suggests a collaborative approach to screening methods would be beneficial.

Clinical evaluation of a concussive event relies on many different information sources; trainers, coaches, collision witnesses, data from instruments and the victim's own reports of symptoms, these all combining to make concussion very difficult to diagnose (Budinger, 2016).

The symptoms of concussion have such a wide range of variability that it is very difficult to corroborate a test that is sensitive enough to capture all of these symptoms (Cross et al., 2015). Therefore, suggesting the use of multiple tests to capture these symptoms may be a new and inventive way for professional athlete's symptoms to be captured post-concussive episode. This will enable heightened tracking and management through a more clinical process, starting critically with baseline screening.

Budinger, (2016) suggests, Diagnosis of concussion currently relies on multiple clinical "symptoms and signs" these are:

- Cognitive: concentration, memory, information processing, executive function
- Motor: reaction time, coordination
- Vestibular: balance, dizziness, vision/ oculomotor function
- Physical: headache, neck pain, sleep disturbance

By continually showing that even within each element of Cognitive, Motor, Vestibular and Physical, there are also two to three subcategories to consider. It is apparent that an TBI is a very vast field of investigation. Recommending an innovative multidisciplinary program that enables all these elements to be addressed is a good way to conduct research.

Research into concussion is only in its infancy and gaining a true understanding of concussion symptomology and the effects it has on an individual are so varied from one person to the next and the length of symptoms also vary. Therefore, currently we know little about the future of an individual who has had a concussion or multiple concussions.

Many people would have come across the phrases "punch drunk," "goofy," and "slug nutter" (Critchley, 1957 and Parker, 1934). Chronic traumatic encephalopathy (CTE) as it is now known in the medical world, comes after years and decades of exposure to repeated head injuries (McKee, 2016). CTE is a neurodegenerative disease that occurs not from a specific number of concussions but from the repeated exposures to head trauma boxers and military men have suffered. This has been linked in midlife with CTE and produces clinical dysfunctions in memory loss, depression, irritability, disinhibition, and Parkinson’s (McKee, 2016 and Stern et al., 2013). Second impact syndrome (SIS) is a secondary concussion incurred by someone who is still not over the first head injury and may be asymptomatic. SIS can happen within any sport and any kind of head injury (Cantu and Hyman 2012; Guskiewicz 2003; Young et al., 2014). This shows that anyone participating in a sport with the potential for head impact is at risk of SIS, therefore, making the management and the rehabilitation of sports players a key component within any research relating to sport and concussion is important. Furthermore, with SIS occurring, a baseline test to provide the ability to compare results may assist with understanding in diagnosing the severity and varying symptomology between concussions.

Cognitive impairment and functions have been shown to be affected when concussed. Gueskiewicz et al., (2005) investigated whether cognitive impairment (CI) and Alzheimer's disease was related to recurrent concussive episodes. They investigated a pool of 2552 retired professional American football players and some 61% had sustained at least 1 concussion previously and 24% had sustained three or more concussions. Statistical analysis of the data identified an association between recurrent concussion and clinically diagnosed mild cognitive impairment (MCI) ($\chi2 = 7.82$, $df = 2$, $P = 0.02$) and self-reported significant memory impairments ($\chi2 = 19.75$, $df = 2$, $P = 0.001$). All retired players that had sustained three or more concussions had a significant predominance of CI diagnosis, in line with significant memory problems when compared to people without a history of concussions. Data didn't show a significant relationship however between Alzheimer's disease in the American football retirees and the general male public. More recently Gallo et al., (2020) conducted a systematic review into the long-term cognitive impairment of athletes which included, 14 studies. Contact and non-contact sports studied were rugby, American football, ice hockey players, boxers and martial art fighters. Results showed that the general quality of evidence was poor and data on non-contact sports was sparse, suggesting more research is needed into non-contact head impact sports such as cricket.

Within high-level ‘batting’ sports such as Cricket and Baseball, motor skills such as reaction time and coordination are both key to performance. The effects of concussion on these skills were tested in a study by Wasserman et al., (2015). They identified Major league baseball players (MBL) who had sustained a concussion between the years of 2007 and 2013. There were 66 concussions recorded and 68 bereavement and paternity leaves recorded. Two similar groups of athletes were compared, and concussed players were compared to players that went on paternity or bereavement leave between the same years. The methods used compared 7 batting metrics and the 2 groups were tested at 2 weeks after return to play and then 4 weeks and 6 weeks after returning to play. Results showed that the batting averages of the concussed players were significantly lower compared to the bereavement/ paternity players within the 2 weeks after returning. Within weeks 4 to 6 however, the metrics were slightly lower in the concussed players but not significantly different. The results show that even though an athlete may be asymptomatic the surplus effects of the concussive episodes may still be present.

Musculoskeletal injuries to athletes are common within organised sports or during individual exercise. Herman et al., (2015) suggest disturbance in the normal patterns of neurocognitive performance can increase the risk of musculoskeletal injury to athletes. They suggest that once an athlete has a disturbance in normal neurocognitive functioning, the musculoskeletal system will be dampened and coordination and reaction time will be suppressed, therefore increasing the risk of another injury.

Vestibular disturbances are very common after a concussion has occurred and symptoms such as dizziness and balance can leave someone very disorientated and incapacitated to do anything at all. The return to everyday life can be a problem and the rehabilitation process to gain homeostasis once again is a complicated one. According to Alsalaheen et al., (2010) who conducted vestibular rehabilitation on 114 patients, results showed an improvement in all self-reported, gait, and balance performance measures at the time of discharge from referral ($P < .05$). These vestibular defects have also been shown to worsen within patients who have had multiple concussions thereby taking much longer to get over symptoms compared to patients with a first concussion (Corwin, et al., 2015). The use of baseline tests such as a single leg balance test could not only help to diagnose a concussive episode, but avoid other injuries due to impaired motor control caused by the disturbance.

Physical effects within concussion have a strong link to sleep disorders, effecting between 30% to 80% of people with TBI (Tkachenko, et al., 2015). Post WW2 TBI have shown a negative influence on sleep and may even cause insomnia. Bryan, (2013) categorized three groups of military personal: no TBI (n= 18), single TBI (n=54) and multiple TBI (n=78). The 150 personnel observed were males serving in Iraq. The results showed that as the frequency of concussion increased so did the severity of sleep disturbance: 5.6% for no TBIs; 20.4% for single TBI; 50.0% for multiple TBIs. Sleep duration and quality of sleep is a key factor as a performance indicator the average athlete's sleep duration and quality was found questionable within Rugby Union, Rugby 7s and Cricket when it was reported that if 7.9 ± 1.3 h of sleep per night was the optimum then 50% of athletes were having poor sleep (Swinbourne et al., 2015). Poor sleep patterns coupled with vestibular problems could potentially severely affect future performance so there is potential here for future research into concussion, sleep quality and performance.

Headache and neck pain are two symptoms that may concern physicians rehabilitating patients. Calati et al., (2015) conducted a meta-analysis on the impact of physical pain on suicidal thoughts, finding that people with headache and neck pain were more likely to report thoughts of suicidal death. This shows that TBI could also have links to other medical, physiological, and psychological symptomology in other areas of medicine.

Post-traumatic headaches (PTHAs) are a very common symptom following TBI with most self-resolving (Dave et al., 2019). However, there are some patients that progress to have chronic headaches and the reason for this is unknown. There is also a strong link between headache and neck pain, and it can present as a tension headache. Current rehabilitation strategies are pharmacological using analgesics, and non-pharmacological with physio and massage.

Research literature shows an increase in symptomology and severe persistent symptomology in patients and athletes that have suffered multiple episodes of concussion. CTE is just one of the major diseases linked to multiple episodes of concussion and most cognitive deficits are found in memory executive functioning and attention, with about 45% of subjects developing dementia in later life (McKee, 2016). It may be right to predict that athletes with multiple concussive episodes may suffer from future health issues due to the accumulation of concussions they have suffered. Research within neurological conditions such as concussion and the issues involving the subject is going to have a positive benefit for patients and drive future research. Only time and future research can help ensure that this is researched and recorded for future generations.

2.4 MRI scanning as a tool within concussion

Neuroimaging scans of the brain can be classified as structural or functional (Solomon et al., 2006). The structural measure of brain functioning is usually conducted through Computed Tomography (CT) scans and more recently Magnetic Resonance Imaging (MRI) scans (Figure 2.1). These types of scans are usually conducted after a concussion in a Brain Injury (BI) and they are often used to rule out any presence of a brain bleed or other medical conditions (Solomon et al., 2006).

Within concussion, scanning is usually standard practise for patients with persistent symptomology of concussion after rest and recovery timeframes haven't worked, or in the initial acute phase of the TBI to rule out any lesions or to investigate trauma to the brain (Taso et al., 2019). Diffusion tensor imagining (DTI) (Figure 2.2) is a type of technique used within MRI scanning and is used to identify axonal and white matter injury not detectable on regular T1, T2, or FLAIR sequences (Taso et al., 2016).

MRI Spectroscopy

- MR spectroscopy provides a measure of brain chemistry. Proton MRS can be performed within 10-15 minutes and can be added on to conventional MR imaging protocols. It can be used to serially monitor biochemical changes that occur in concussion / head injury as well as tumours, stroke, epilepsy, metabolic disorders, infections, and neurodegenerative diseases. The MR spectra do not come labelled with diagnoses, as such, and therefore require interpretation and should always be correlated with the MR images before making a final diagnosis.

- MRS is helpful to assess the degree of neuronal injury and predict patient outcomes. In the case of certain head injuries (diffuse axonal injury), conventional imaging often underestimates the degree of brain damage. However, clinical outcome correlates inversely with the NAA/Cr ratio and the presence of any lactate or lipid indicates a worse prognosis. These are seen with MRS.
- MR spectroscopy as used in this study does not replace CT and MR imaging needed to demonstrate the fractures and intracranial haemorrhage that require immediate surgical intervention

Figure 2.1 Images from a Magnetic Resonance Spectroscopy Scan (Ch choline ml is millilitres, Cr is creatinine, Glx glucose NAA, N-acetyl-alanine, Lac Lactose.)

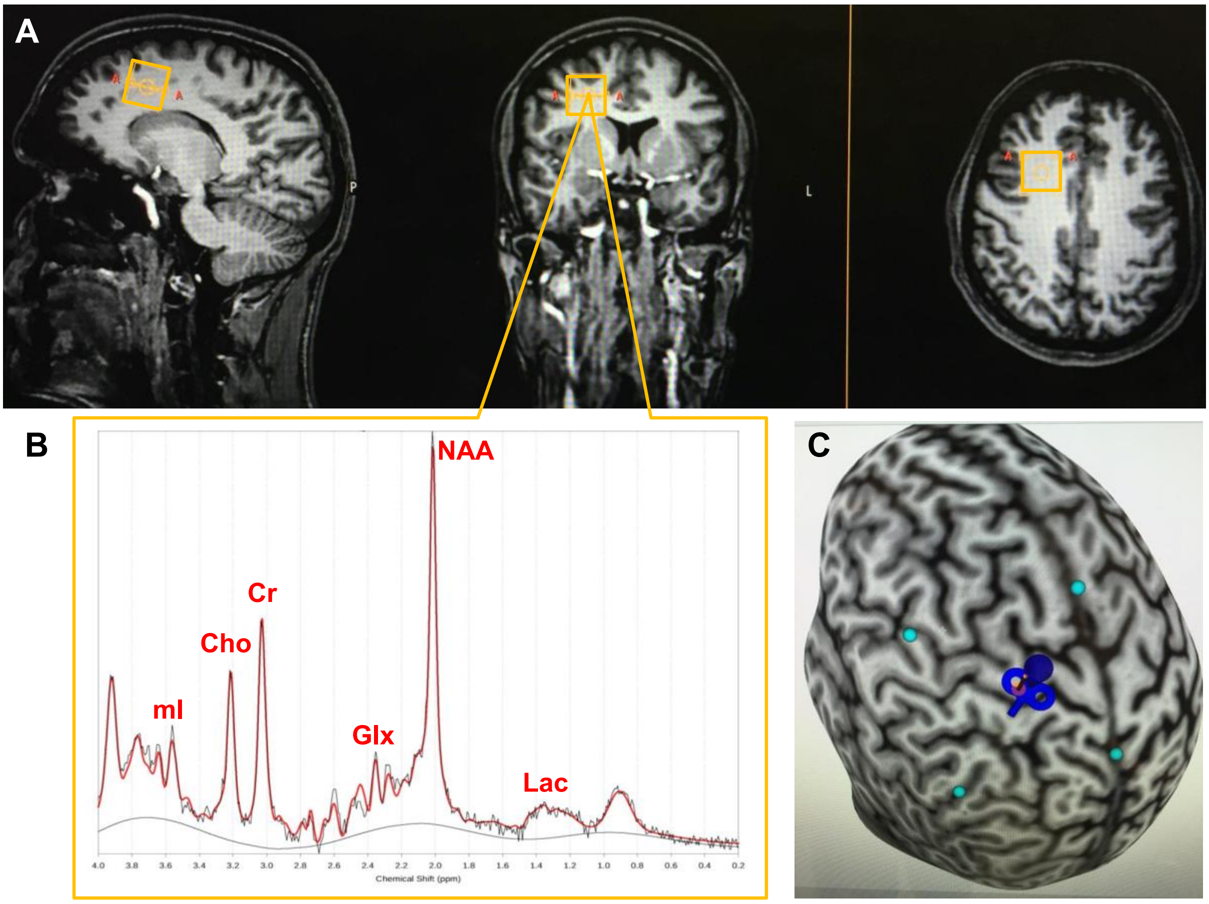
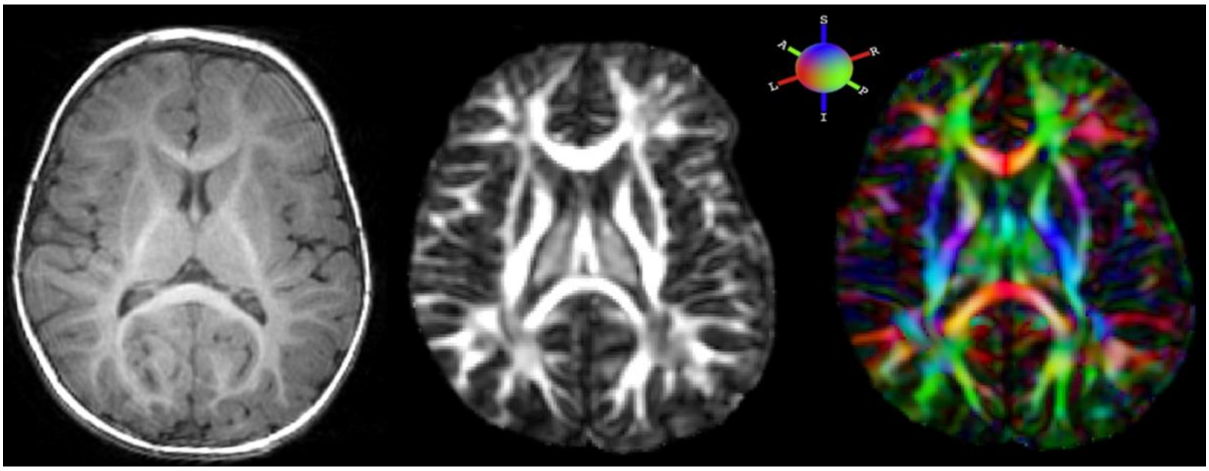


Figure 2.2. Images from a Diffusion Tensor Imaging Scan



White matter is thought to be a passive brain tissue and affects learning and brain function but can affect action as it acts as a relay communication system between varying parts of the brain (Fields, 2008). Bazarian et al., (2012) showed subject-specific changes in brain white matter using DTI after a sports-related concussion and scanning took place pre and post-football season. All nine patients were scanned within 73 hours post-concussion. Results showed white matter was highest within the concussed athletes ($p<.05$). pre-post changes were highest for the concussion subjects (3.2%), intermediary for those with sub concussive head blows (mean 1.05%±.15%) and lowest for controls (mean 0.28%±.01%). The conclusion was that white matter was more noticeable in athletes who had sustained single head blows while athletes with multiple head blows had significant percentage differences in white matter suggesting that relay and communication systems between varying parts of the brain could be comprised. This makes imaging a fantastic way of gaining insight into the potential trauma sustained through a TBI.

2.5 Head injuries within the NHS and sports-related concussion

An agreed definition of concussion is 'a temporary disruption in normal brain function after a mechanical impact or transmission of force through cerebral tissue'. Mild traumatic brain injury (mTBI) is also known as a concussion (Bazarian et al., 2012). Diagnosis of concussion relies heavily on the patient's level of knowledge and understanding of signs and symptoms, which fall under 5 categories:

- Sleep disturbance (trouble sleeping or drowsiness)
- Somatic (headache, nausea, visual problems, balance problems dizziness and sensitivity to light and noise)
- Emotional (more emotional than normal, crying)
- Cognitive (trouble concentrating and remembering, 'foggy' sensation)
- Physical symptoms (amnesia)

These symptoms are vast and ever-changing depending on impact and focus, injury type and patient's medical history (McCrory et al., 2012).

Maxillofacial injuries occur at high rates throughout the year and NHS departments across the UK are seeing a significant increase in levels of cycle trauma within research over a 10-year period (Dodds et al., 2019). Road Traffic Accidents (RTAs) make up 88% of injuries and motorbike incidents are the most frequent (Exadaktylo et al., 2004).

Concussion is one of the most common forms of neurological injury seen across the world. Sojka, (2011) showed that both "sports-related" and "non-sports related" concussions have similar signs and symptoms but different management strategies. The current drive of research within concussion is primarily aimed towards the diagnosis and management of concussion in sport (McCrory et al., 2012). Within the NHS, Hammond, et al., in 2016 stated that 5% of patients with TBI unexpectedly return to the Emergency Department within 72 hours of discharge, and of those some 5% required admission. Within the USA there are 1.4 million presentations to the Emergency Department with TBI per year and 80% of these are TBI which suggests a significant public health problem. The specific area of concern appears to be the diagnosis, and there appears a limited level of evidence around these areas (Eliyahu et al., 2016). Diagnosing a concussion relies on the assessment of a physician obtaining information from the patients on symptomology, vestibular disturbances and cognitive functioning. This is a lot easier within a professional sporting environment due to the full-time management and monitoring of player welfare. Within the NHS and daily life of non-professional sports players the question must be asked about the levels of knowledge and understanding in and around the topical area. Gaining a global understanding of knowledge within the public and professional sectors would only benefit future research.

Delayed symptoms can occur and links with depression and anxiety Guskiewicz (2007) and Broshek (2015) have been reported within patients sustaining multiple concussions. Second impact syndrome (SIS) has a strong link to the brain degenerative diseases commonly seen in elderly people, such as Alzheimer and Parkinson diseases (Tator, 2013). This suggests that early diagnosis and correct concussion management is paramount for long-term health and wellbeing of any human whether a professional athlete or public citizen.

2.6 Predicting concussion

Aggarwal et al., (2020) used age, sex and ADHD markers to try and predict recovery time post concussive incident. However, the study was inconclusive even though shorter recovery times were predicted by Hispanic and African American races, thus indicating further research into concussion recovery and ethnicity should be conducted as a potential indicator for recovery time. Furthermore, Ono et al., (2015) conducted similar research into whether sex played a part in recovery from concussion and found no significant difference in the longitudinal slope in the time frame of recovery between gender but there was a difference in increased awareness of symptomology between male and females with females showing increased awareness. Benedict et al., (2015) used various assessment tools: 3rd Edition (SCAT3); a vision-based test of rapid number naming (King–Devick [K-D]; Symptom Evaluation; Standardized Assessment of Concussion (SAC); modified Balance Error Scoring System (BESS); to evaluate sports and non- sports concussion in patients in an outpatient's clinic. They found that age and gender were predictors of outcomes for all of these tests. The results showed that a greater number of symptoms were associated with older age ($r = 0.31$, $P = 0.002$), and female gender ($P = 0.002$, t-test), and also a longer time between the concussive event and the first appointment at the concussion centre ($r = 0.34$, $P = 0.008$). This research showed that these tests could be useful for future research, and the longer waiting time for patients with stronger symptoms needs to be addressed. Stevens et al., (2008) suggest that game time was a good predictor of concussion with a large data pool of 787 NHL players in 2001-2002 examined. They showed that a player's average ice time was a better predictor with no significant difference found between the number of games played within a season.

Sufrinko et al., (2019) recently conducted a study in to whether or not pre-existing conditions such as motion sickness could predict vestibular dysfunctions following sports or recreation-related concussion. Early results showed that there was no association between motion sickness and vestibular/oculomotor screening scores (VOMS) score at 1 - 10 days post-injury. However, at days 11-20 there was found to be a significant relationship between motion sickness and VOMS items (P values 0.01-0.04). In summary pre-existing history of motion sickness may exhibit prolonged vestibular dysfunction and may present more severe symptoms early in recovery from concussion. Therefore, this may help doctors when prescribing anti-sickness drugs for patients with concussion.

Literature has shown some positive research on how to protect and prevent a concussion. Collins et al., (2014) concluded that neck strengthening through exercise decreased the odds of a concussion by 5% for every pound of increase in neck strength. Furthermore, they stated that identification of athletes through screening and developing a tool for neck strength could be a valid predictor for avoiding a concussion. This however, is a bold statement due to the varying and vast ways of a concussion occurring to an individual. As previously stated, concussions do not occur in one particular way, so neck strength becoming a predictor of avoidance of a concussion may not be reliable, further investigation would be needed. Regardless of protective equipment, sex, age and strength training, sports medicine practitioners around the world work within their sports bodies to make sport safer, through rule changes or proper sporting techniques (Cross and Serenelli, (2003). Rules have been changed in many sports such as the tackle change in Rugby Union (2019) which states that all tackles must be around the waist or lower, or the referee will penalise the illegal tackle (Reive, 2019). In the American Football League, the tackle law also changed, with a reckless hit bringing an immediate ejection from the game. Rule changes are often a highly debated topic between sports fans, however the duty of care of sports medicine practitioners toward the athletes through research-driven interventions must be a priority, despite some rejection from media and fans. Throughout history, sports usually change rules to make them more appealing for tickets sales, but due to research and player associations such as the Rugby Players Association, sports are trying to make changes that benefit the athlete's health bringing more validation to testing and research.

2.7 Concussion recovery and treatment

The mechanisms set in motion when a concussion occurs are very complex. The impact force, the biomechanics of the incident, and the patient's existing history of TBI are just a few of the areas that could have an impact on the severity of a concussion. They affect not just the neurons directly injured but also areas of the brain that are far removed from the lesion site through processes such as trans neuronal degeneration, neurochemical alterations, oedema, raised ICP, and vascular disruption due to haemorrhage or ischaemia (Ponsford, 2013). Brooks and Aughton, (1979) state that due to the extended variability in recovery curves, it is difficult to predict recovery lengths, time course and the pattern of injury.

There are no approved therapies for TBI and trials of all pharmaceutical remedies to treat concussion / TBI have failed (Budinger, 2014). There isn't any agreed return to work protocols within the NHS, however, sports do seem to be ahead of the curve slightly as some sports have adapted and trialled their own return to training and playing processes. The main elements of rehabilitation from a TBI seem to be rest and a progressive return to the ordinary life of the individual. With most concussions resolving within 2 to 4 weeks, cognitive and physical rest seems to work for these patients and the majority become asymptomatic. However, some 10% to 33% have persistent symptoms for many months; this is known as post-concussion syndrome (Prince et al., 2020).

Most literature has focused on injury incidences and the recovery patterns of patients (Broglio et al., 2015). Nevertheless, it is still deemed essential that patients in the first stages of a concussion have total physiological and cognitive rest (Broglio et al., 2015). Patients with persistent vestibular issues of dizziness and imbalance have tried to rehabilitate with vestibular treatments and progressive exercise programs such as eye-head coordination, standing static balance exercise and ambulation exercises. Alsalaheen et al., (2013) conducted a study of 104 participants with exercises that had been prescribed by clinical professionals. The findings were inconclusive and showed further research needed to be conducted. However, the vestibular exercises used and modified were an exceptional way of introducing a

methodological approach to integrating a patient back to normal day-to-day life.

This suggests that baseline testing will be a good way to compare and contrast results obtained in a methodological research approach.

Treatment of TBI has its own current limitations and the varying stages that symptoms occur makes treatment very difficult. The treatment and recovery processes of concussion remain persistent challenges. Different disciplines need to join together to allow research of materials, mechanics and modelling so we can gain a more complete understanding of the injury and its treatments.

Graduated return to play guidelines within Rugby Union were created by World Rugby for clinical physicians to use (World Rugby Concussion Guidelines Putting Players First, 2021). The Graduated Return to Play protocol is a 6-phase process which describes a methodological approach to recovery and returning to play Rugby. Cross et al., (2019) discussed a group of 117 Professional Rugby players and 105 (95%) progressed through all the 6 phases demonstrating that overall, the process works. However, 6 players became symptomatic again and 24 players required multiple neurocognitive testing (19 did not meet baseline testing scores with 5 declaring symptoms during the tests). World Rugby concluded that they had a valid and strategic process of returning players to match fitness within a sporting context but acknowledged that with a pool of only 117 participants further research was required. Literature is lacking on graduated return to play protocols in other sports such as cricket.

2.8 Sports-related injuries and concussion

The drive of concussion research seems to be aimed at better diagnosis and management for concussion in sport (McCrory et al., 2013). Hill et al., (1998) stated that concussion is more frequent in cricket than first expected with 92 head impacts (29 concussions) in men's matches. However, it didn't include training hours which suggests a lack of deeper understanding within the sport. Furthermore, as the pool of male athletes was only 179 players a more in-depth analysis is needed to gain a true reflection the rates of concussion in cricket. The increased rate of concussion could also be due to increased awareness of concussion within Cricket as the study was performed over the 2015 - 2016 season just after Australia cricket launched an investigation into the frequency of concussive episodes and made it a priority due to the death of Phillip Hughes in 2014. This is further highlighted in a study by Tripathi et al., (2016) with literature and internet searches looking for information of craniofacial injury and concussion in professional, county and first-class cricket worldwide. Results revealed only 36 events of head injuries in 45 years (1870-2015). This compared to 92 head impacts in 2 years by Hill et al., (2018). This reinforces the suggestion of a lack of understanding of head impacts and concussion in cricket at all levels in previous years.

The cranium is typically the most uncovered part of the body when participating in sports and thus is at the highest risk of getting damaged or exposed to a concussion. However, there seem to be many factors that influence this as witnessed by different research study findings. Emergency Departments witness a lot of sports-related injuries across the world. In the Netherlands sports-related injuries account for 3% of attendances, in the UK over 1% and in the USA some 12% (Van den Bergh et al., 2012; Echlin and McKeag 2004 and Hill et al., 1998). Rugby in both Australia and Ireland is responsible for the numerous maxillofacial fractures found within their Emergency Departments (Carrol et al., 1995 and Lim et al., 1993). This is also closely followed by Cricket and Soccer injuries.

Contact sports such as Rugby Union are very popular throughout the world and in New Zealand, 50% of maxillofacial injuries occur through playing Rugby Union (Lee, 2008). This suggests that there might be a connection between maxillofacial injuries and concussion because of the impact area. This is further made apparent with a clash of heads or being struck by the elbow which are the most common causes of concussions in Soccer and Basketball. This gives purpose for future research between "non-contact" sports and “sports-related” concussion incidents as these impacts could potentially lead to a concussive episode (Cerulli et al., 2002; Guyette, 1993 and San et al., 1987).

Collision sports such as American Football, Rugby Union and Ice Hockey have been linked with brain trauma since the 1880s when it was reported that 18 deaths and 159 serious injuries from college football were sustained in the first 10-year period of the first American football games played between Harvard University and Pennsylvania University (Harrison, 2014).

The consensus definition of concussion was only agreed in 2001 which makes the subject somewhat undeveloped. Only recently have we had enough of an understanding of the signs and symptoms to diagnose concussive episodes retrospectively throughout history (Turner, 2019).

However, over the past decade, many concussive episodes in sport may have been missed due to a lack of education and understanding. An increase in concussive episodes was recorded between 2006-2016 with the largest increase seen in 2015-16 (Orchard et al., 2016). The risk to athletes of longer-term neurodegenerative conditions through repetitive concussive episodes is now recognised within contact sports. Further investigation into concussion and elite cricket athletes is now a priority to see if the effects seen in other sports (Lehman et al., 2012) are prevalent. Maladiere et al., (2001) suggests "non-contact" sports may also share some risk factors such as falling to the ground. It is very important not to neglect the possibilities of concussion occurring during non-contact sports such as Soccer, Basketball and Cricket.

Concussion in Cricket has been actively under review since the tragic loss of Phillip Hughes. The Australian International Cricket player passed away in 2014 after being struck just beneath the left ear by a “bouncer” cricket ball. He was rushed into hospital in Sydney where he was unconscious for two days before sadly passing away. As a result, concussion is also becoming increasingly recognised throughout many sports such as American Football, Rugby Union, Football (Soccer) and Cricket (Colello et al., 2018; Gallo et al., 2017; Orchard et al., 2016 and Williams, 2010).

A study by Hill et al., (2018) suggested that concussion was more common in Cricket than the literature suggests. The study looked at elite level male and female cricket players within Australian Cricket over two playing seasons (2015-2016 and 2016-2017). A total of 351 males and 204 females were included in the study (both domestic and international). The study showed that there was a higher rate of concussion in female cricket. Concussion rates per 1000 hours played were 0.4 for elite males and 0.5 for elite females. Male players sustained 2.3 concussions and females 3.7 over 1000 hours played. This equated to a head impact every 2000 balls and concussion every 9000 balls.

In a similar study in Rugby Union over a four-season period (2012/2013-2015/2016) at the elite level and over 1000 hours of match play, Rafferty, (2019) found that players were at a greater risk of sustaining a concussion than not after an exposure of 25 matches (95% CI 19 to 32). Injury risk (any injury) was 38% greater (HR 1.38; 95% CI 1.21 to 1.56) following concussion than after a non-concussive injury showing that there is a much higher risk of concussion within Rugby than in Cricket. However, with concussion having only been researched recently in cricket and with minimal data currently available, research into the levels of knowledge and understanding might be relevant in future research.

Cross et al., (2015) conducted research into concussion incidences within Rugby Union and the percentage of reoccurrence of injuries over a 2-season prospective study. Results showed that match concussion rates per 1000 hrs were 8.9/1000 with over 50% of concussions occurring in the tackle. Shockingly suffering from a concussion was not the only issue but of those players returning within the same season following a concussion some 60% of players were at greater risk of a time-loss injury compared to players without a concussion returning within the same season. In addition, a staggering 38% of players also reported a recurrence of concussive symptoms or even failed to reach their baseline neurocognitive test scores during graduated return to play. With athletes at a 60% greater risk of injury post-concussion, it would be beneficial to contextualise these injuries into classification, pathology and occurrence to allow an understanding of injuries versus time loss injuries.

2.9 Concomitant of injury

A 10-year review in 2003 suggested that 19.6% of cranio-maxillofacial trauma patients have concomitant injuries, particularly cerebral and cervical-spine injuries and almost 10% of these patients sustain intracranial haemorrhages (Gassner et al., (2003). Road traffic accidents are the most frequent cause of injury among cyclists where fractures of the skull with brain contusions are common, but contusion of the thorax with rib fractures and injuries to the upper and lower extremities are not uncommon (Lizuka et al., 1990).

While sports-related non-maxillofacial injuries diagnosed at the time of maxillofacial trauma may be less frequently life-threatening than those due to road traffic or work-related accident, some 6.4% of patients with sports-related injuries also have life-threatening non-maxillofacial injuries (Mourouzis and Koumoura, 2005).

A UK study in 1998 reported that the most common sports-related maxillofacial injuries were soft-tissue trauma (80%), dentoalveolar injuries (11%) and facial fractures (9%) (Hill et al., 1998). Sports-related fractures most often involve the mandible, followed by the zygoma, Tanaka et al., (1996); Maladiere et al., (2001); Sane and Ylipaavalniemi, (1987) and a fracture to the angle of the mandible is particularly common in rugby (Lee, 2008). In football, zygomatic arch and nasal fractures are common, Cerulli et al., (2002) most often due to elbow or head contact while trying to head the ball.

The head and the jaws are common areas of impact in cricket so future research into cricket helmet design should concentrate on protecting these areas. In reviews of maxillofacial fractures sustained in ball sports the most frequent site of mandibular fracture was the angle, followed by the condyle (Tanaka et al., 1996; Delilbasi et al., 2004). Emshoff et al., (1997) reported that in skiing and cycling, the subcondylar region was most commonly affected (Emshoff et al., 1997). However, skiers and cyclists wear safety helmets that cover the chin and protect the condylar process. In one of the older studies of some 319 mandibular fractures, Hagan and Huelke in 1961 identified certain fracture patterns:

- The condyle is the commonest site
- The angle is the second most common
- However, if there is only one fracture, the angle is the most common site
- Multiple fractures are more common than single fractures (ratio 2:1)

A seminal paper in the late 19th century by René Le Fort described three lines of midface fracture, which he identified by dropping cannon balls onto the faces of dead convicts. While this methodology is unlikely to pass an ethical committee today, his work remains relevant. He named the fracture lines Le Fort I, II and III:

- Le Fort I fracture passes through the base of the nose and continue through the pterygoid plates, separating the tooth-borne area and palatal part of the maxilla from the midface.
- Le Fort II fracture, which is pyramidal in shape, passes through the maxillary sinuses, medial wall of the orbit and lower part of the nasal bridge, and through the pterygoid plates.
- Le Fort III fracture separate the midface from the upper and lower face on a line running through the zygomatic arch and zygomaticofrontal suture, both medial and lateral orbital walls, the upper aspect of the nasal bones and the upper surface of the pterygoid plates.

Le Fort-type injuries are most commonly seen in mountain-bike accidents (Gassner et al., 2003). Finally, horse riding and, in particular, horse-kick injuries which can lead to significant maxillofacial trauma (Lim et al., 1993).

2.10 Treatment and rehabilitation of facial fractures

Fractured mandible

This is likely to necessitate hospital admission, followed by surgery within 24–48 hours of injury. The mandible is usually an open fracture, as the overlying mucosa is often torn, making early preoperative antibiotics key. The operation of choice is most frequently open reduction and internal fixation of the mandible, with or without intermaxillary fixation. The patient is likely to remain in hospital for 24 hours postoperatively and have a review at 1 week. No sports training is advised for 4 weeks post-surgery. Heavy weights can recommence at 6–8 weeks post-surgery, with a return to contact after 8 weeks (Clover and Wall, 2010).

Fractured zygoma

The patient is likely to be reviewed 3–5 days post-injury to assess asymmetry and function. In the interim they will have been advised not to blow their nose to allow the swelling to reduce. The rationale for surgery is either:

a) Function, due to trismus caused by the zygomatic arch impinging on the coronoid process of the mandible; or
b) Aesthetics, to restore facial asymmetry.

Paraesthesia or anaesthesia of the infraorbital region are not indications for surgery. The operation of choice is open reduction and internal fixation of the zygomatic complex. This is done by a variety of approaches and can result either in no fixation (pure arch fracture) or one-, two- or three-point fixation, depending on the stability of the fracture.

The patient is likely to remain in hospital overnight, before returning for review at 1 week. Unless a mask has been custom-made to prevent injury damage, non-contact training can recommence at 2–3 weeks, followed by contact-based training at 6–8 weeks post-surgery (Mahmood, Keith and Lello, 2002).

Fractured orbit

The patient is likely to be reviewed 3–5 days post-injury. In the interim they will have been advised not to blow their nose, had a CT scan of the orbits and an orthoptic assessment of visual fields to check for ocular muscle entrapment. If surgery is required, the patient will probably have open reduction and internal fixation of the orbital floor and will remain in hospital overnight. The patient will be reviewed 1-week post-surgery; non-contact training can start at 2–3 weeks, and contact-based training at 8 weeks (Mahmood, Keith and Lello, 2002).

Fractured nasal bones

The patient is likely to be assessed at 5 days post-injury. Aesthetics and airflow will be reviewed. If required, a closed manipulation under general anaesthesia will be performed. Non-contact training can resume after 1 week, and contact after a further week, in spite of the risk of re-injury (Clover and Wall, 2010). The other option, if aesthetics rather than airflow is the issue, is to allow the fracture to heal and have an open procedure at the end of the sporting season.

2.11 Prevention of maxillofacial injury

Prevention is preferable to surgical cure post injury, and so continued research and investigation into the use of mouth guards for preventing facial injury in sport is critical. They reduce soft-tissue and dentoalveolar injuries, Marshall et al., (2005) and mandibular fractures, Ranalli and Demas (2002) by holding the soft tissues away from the teeth and bracing the jaw to dissipate forces. There is clear evidence that custom-made mouth guards are superior to over-the-counter devices (Tuna and Ozel, 2014). Furthermore, continued research and innovation in helmet design in cricket can only have a beneficial outcome. Research in Ice Hockey showed that helmets and visors were better facial protectors than cages in reducing severity and incidence of head trauma and as a result, players are better protected than previously (Lemair and Pearsall, 2007).

2.12 Protective equipment and sports concussion

Death within sport is rare but the loss of the Australian cricketer Phil Hughes in 2014 has brought increased media scrutiny to the sport of Professional Cricket. Historically contact sports such as Rugby Union, Rugby League, American football, Ice hockey and combat sports are the main causes of maxillofacial injury, and its accompanying concussion.

The face is usually the most exposed part of the body when playing any sport. However, the frequency of facial involvement in sporting injuries varies between studies, countries, and different sports, and is influenced by the popularity of some individual sports. In the USA, approximately 12% of maxillofacial traumas seen in the emergency department are due to sports-related injury (Echlin and McKeag, 2004). In the Netherlands, the figure is 3%, (Van den Bergh et al., 2012) while in the UK it is 1% (Hill et al., 1998). In Australia and Ireland, (Carrol et al., 1995; Lim et al., 1993) rugby is the sport responsible for the most maxillofacial fractures, followed by cricket and soccer respectively. In Japanese and British studies, (Hill et al., 1998); Tanaka et al 1996) rugby confers the highest fracture risk and in New Zealand, Rugby is so popular that over 50% of maxillofacial sports injuries are associated with the sport (Lee, 2008). Conversely in Finland, (Sane et al., 1988) France, (Maladiere et al., 2001) and Italy, (Cerulli et al., 2002) the greatest maxillofacial fracture risk is associated with soccer, while in Switzerland the most common cause of sports-related maxillofacial injuries is skiing and snowboarding (Exadaktylos et al., 2004).

Team rather than individual sports have a higher incidence of maxillofacial fractures and impacts with other players is the most frequent cause (Cerulli et al., 2020; Guyette 1993; Sane et al., (1987). A clash of heads and being struck by an elbow of an opposition player are the most common causes of maxillofacial injuries in soccer and basketball, respectively. Conversely, injuries resulting from falls to the ground occur mainly during non-contact sports (Maladiere et al., 2001). Injuries due to contact with game accessories or equipment, such as the ball or posts, are rare but the majority occur in soccer and hockey.

Serious injury associated with maxillofacial injuries is not uncommon and Mourouzis and Koumoura, (2005) reported intracranial haemorrhages in 13.8% of sports-related maxillofacial fractures. In sports related maxillofacial injuries some, 3.6%–7.2% had multiple facial fractures, (Carrol et al., 1995); Tanaka et al., 1996) and generally the more severe injuries are commoner in ice and snow sports and cycling (Tanaka et al., (1996).

Within the last 15 years cricket helmets have become an accepted piece of protective equipment and questions have started to arise about protective equipment generally to reduce maxillofacial injuries and concussive episodes (Tripathi et al., 2016).

Dennis Amiss a Warwickshire and England cricketer was the first player to wear a cricket helmet for protection in 1977. He decided to wear an old motorcycle helmet to protect himself from the fast bowling of the West Indies and Australia (Talati, 2019).

Protective equipment within the sports world is not only a requirement in certain sports such as ice hockey and American football but it also a multi-million-pound business. However, is the equipment making a difference to the incidence of concussion? Research by McCory, (2001) showed that there was no real evidence in the early studies that protective gear such as mouthguards had any protective effect. They concluded that Emergency Departments and sport in general would benefit from education around the topic.

In Skiing and Snowboarding 47% of all injuries sustained are head injuries (Stuart et al., 2020). Sadly, head injuries are also the predominant cause of death in these sports. Therefore, making a protective helmet would be a vital part of any preventive strategy. The study by Stuart et al., (2020) reviewed 766 cases on the snow sports database. "Simple fall", "jump impact" and "impact with object" were the commonest injury mechanics and concussion was the most common injury type. In addition, occipital head impact was associated with increased odds of concussion (OR = 7.46; 95% CI = 4.55-12.56; P = 0.001). The data demonstrated that head injury mechanics are complicated and even with protective equipment concussion still occurs through head impacts.

Protective equipment doesn't get much bigger than in American football where brain injuries are still very prevalent. The American Football helmet is uniquely designed with a deformable outer shell and a stiff inner shell (Giudice et al., 2020) and very similar to cricket helmets with similar shell-like engineering. Helmets have been shown to reduce TBI but we continue to see concussions within sports that wear protective equipment (Taylor, et al., 2019). A review paper by Delaney et al., (2000) reported that nearly 50% of 289 Canadian football who had all worn protective equipment had concussive symptoms during the 1997 season. However, an even higher rate of concussion was shown in a nationwide comprehensive database of 118 American football teams by Dompier et al., (2015). The authors concluded that considering the athlete trained on average more than they played, it was important to limit the player-on-player impacts to reduce the number of concussions.

Tripathi et al., (2016) researched craniofacial injuries in cricket and their aim was to evaluate the history of usage, changes in design and protective value of protective equipment compared to other sports. A total of 36 cases of head injuries were identified: 14% were fatal and 22% were career-ending with batsman the most vulnerable with 86% of the impacts. Tripathi el at, (2016) concluded that craniofacial injuries were a lot more common than once thought, and the need for strict injury interventions were needed so that a universal acceptance could occur, and injuries could be diagnosed effectively. Rehabilitations could then proceed correctly through research-based evidence and equipment could be adapted when required.

2.13 Testing for concussion throughout sport

Medical researchers from around the world strive to develop the best types of diagnostics tools, research methods and testing protocols to improve the health and welfare of athletes throughout the world. Testing protocols allow for a far greater understanding of what actually occurs in and around a concussion. Yakoub et al., (2018) published the protocol for their study which aimed to establish a panel of non-invasive MicroRNA biomarkers in urine and saliva for the rapid diagnosis of concussion. This is being conducted in Rugby Union and final results are awaited. These testing methods have the potential to become a novel diagnostic technique (Yakoub et al, 2018).

Many would prefer to be assessed non-invasively. There are different types of non-invasive testing and two such forms are neurophysiological and neuropsychological testing (Kaminski et al., 2009; Solomon et al., 2008). Neuropsychological baseline testing is quite common within a sport setting and unfortunately a fear of not being able to play due to concussion can get some athletes "sandbagging" the baseline tests. However, Erdal, (2012) showed within the tests used it is extremely difficult to fake the test and concluded that neuropsychological tests can be reliable and accurate. One caveat is that these tests eg.the ImPACT test, don't take into account learning difficulties and attention disorders (Collins et al., 1999).

Neurophysiological tests such as balance coordination tests are all used in baseline testing at pre-season within a number of professional sports to allow athletes to have a baseline score for if injury occurs (Solomon et al., 2008). Key factors that could potentially have an impact on recorded scores are effort and motivation and one study showed poor motivation with 11% of their sample giving minimal effort (Hunt et al., 2007). Schatz et al., (2010) showed that 9% of their sample was invalid due to poor testing. This is something that must be considered when baseline testing is used in any research project. Good explanation, visual tools, demonstrations and a clear understanding of the benefit of testing is key to gaining a quality testing procedure. This further highlights that the participants level of understanding and knowledge of concussion will have an impact on their motivation.

To improve the level of accuracy and detail in testing protocols, patients should always be tested on an individual basis. Baseline data and testing protocols within concussion involve four main areas which concussion is known to impair; neurophysiological factors such as balance, coordination, the reduced speed of ocular processing and movement, cognition and recall (Cross et al., 2015). The Berlin concussion in sports group provided a global statement and outlined best practice in concussion prevention, diagnosis and management underpinned by expert systematic reviews (Patricios et al.,2018).

The Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) (Resch et al., 2013) is a computerised neurocognitive test that is used for evaluating sports-related concussion with documented sensitivity and reliability (Kellor et al., 1971). The test lasts approximately thirty-five minutes making it not too extensive. The test is very varied and measures multiple aspects of cognitive functioning namely Visual Memory, Processing

Speed, Reaction Time, Verbal Memory and Impulse Control. The test should always be administrated as per standardised procedures recommended with the purchase of ImPACT and all scores should be logged and recorded privately and confidentially.

The objective of a cross-sectional study by Cottle et al., (2017) using ImPACT was to determine whether pre-existing factors could influence the individuals score on the test. A large patient pool was obtained through the Collegiate Athletic system in America of 486 student-athletes. Results showed that sex can play a part in verbal memory (P= .001), visual-motor speed (P < .001), and reaction time (P=.006) with women performing better than men. Former patient treatment for pre-existing conditions such as headaches and migraines (P< .001), a psychiatric condition (P < .001), or a diagnosis of attention-deficit/ hyperactivity disorder (P < .001) were all showed to affect the athletes ImPACT score. Individuals running of this test should be conscious that such disorders can affect results of ImPACT testing. (See appendices).

Management of concussion testing for athletes on the field of play can be highly challenging in most sports due to the multiple activities occurring at any one time. An initial on-field fast test is required by the team physicians, doctors or athletic trainers. The Maddock's questions were identified exactly for this reason (Maddocks et al., 1995). Within a 7-year consecutive study (1985-1991) all players at a professional Australian Rules Football club were asked a set of questions evaluating orientation and short-term memory. Concussion was diagnosed independently on the answers given. This is still used as a fast assessment tool for player removal in today's sports. After an athlete is removed from play due to failing the Maddock's questions, the SCAT test would be conducted for a more thorough off-field assessment (Patricios et al., 2018).

The Head Injury Assessment (HIA) screening uses a SCAT 5 (Sports Concussion Assessment Tool) (See appendices 3) test which is used in many sports eg. Rugby Union as a baselining tool (Fuller et al., 2020). It tests all four areas of main brain functions impaired by concussion: balance; coordination; reduced speed of ocular processing and movement; cognition and recall (McCrory et al., 2013). The SCAT 5 is the latest iteration of SCAT and is a tool that is standardised for injured concussed athletes and can be used for all athletes from the age of 13. The SCAT 5 Davis et., (2017) replaced the SCAT 4 in 2017 and was developed by experts from the 5th International Consensus meeting on Concussion in Sport in Berlin (SCAT 4 having previously been developed at the 4th International Consensus meeting in Zurich in 2012). The SCAT takes approximately 15 minutes to complete.

Understanding the central nervous system (CNS) and the way it then feeds back to the brain on mechanisms for maintaining postural equilibrium is one of the first steps in understanding and building a case for objective balance testing procedures (Guskiewicz, 2011). There are three systems which send commands to the muscles to the extremities like the ankle and foot, and which then cause an appropriate contraction to stabilise the body (Hellebrant et al., 1939 and Shumway et al., 1986). Within sport, balance is a key attribute to performance. Balance is described as the ability to maintain the centre of gravity (COG) within the bodies base of support. (Guskiewicz, 2011). The removal of sense interaction, such as from the eye when testing balance removes reliance on this sense during the assessment of balance and postural control. Balance and postural control is reduced in certain pathologic conditions caused by TBI (Ingersoll and Armstrong, 1992).

The Single-Leg Balance Test (SLBT) is performed by an athlete balancing on one leg, hand on hips, with eyes closed (See appendices). This test of balance was validated by a prospective study completed by the Medical Research Council (Cooper et al., 2014). To achieve good balance the feedback from the optic nerve, stretch receptors, and the vestibulocochlear nerve must all be functioning. The purposeful removal of sight input (closing eyes) assesses the function of the two other elements in more detail. This should be done as Teel et al., (2016) and Rosenbaum et al., (2010) suggest. The athlete should always be asked if they have any lower limb injuries or disabilities as this has been seen to impair the ability to perform (Teel et al., 2016). If a participant does then they should not proceed with the testing. The test lasts approximately twenty seconds and should be repeated on each leg (Sambasivan et al., 2015 and Teel et al., 2016).

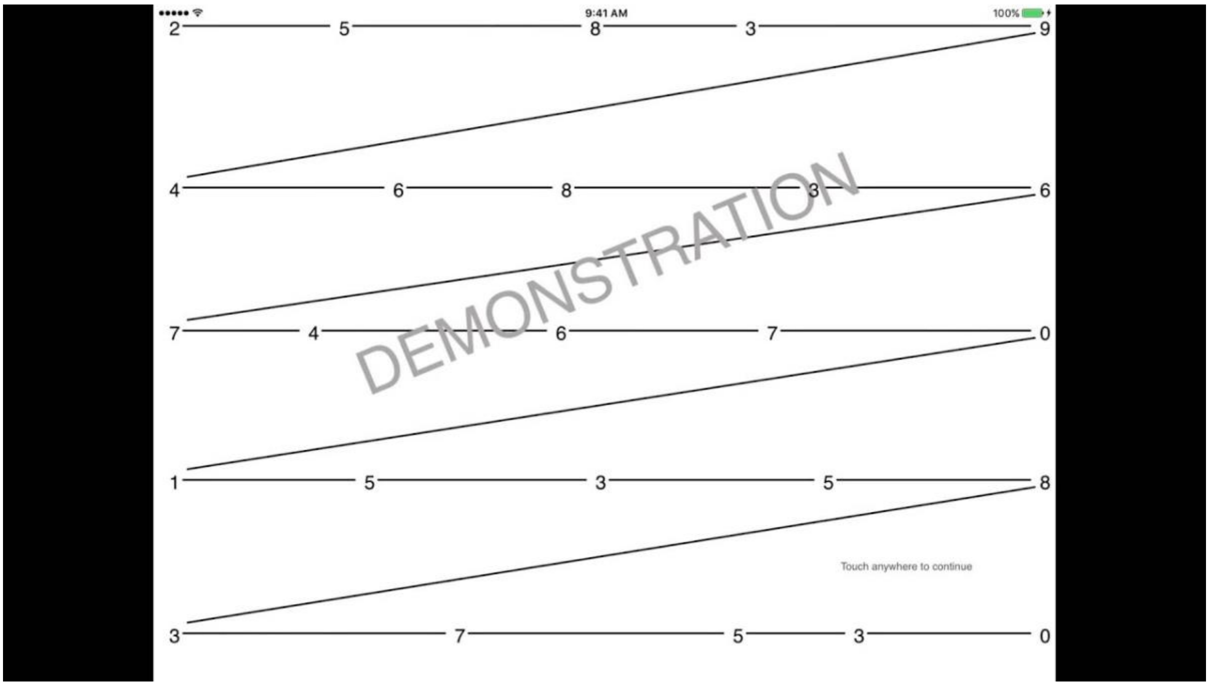
The literature demonstrates that single leg balance is affected by concussion. Martini et al., (2011) showed that the main outcome measures of single leg balance were significantly impacted within a concussed group showing a much shorter single leg balance score. Results showed that people with a concussion will demonstrate poorer gait tests from baseline scores.

Visual disturbances following TBI include vergence (non-strabismic, as well as strabismic), photosensitivity, visual field integrity and ocular health. Other types of rehabilitation such as vestibular, physical and cognitive sometimes having to be put on hold due to persistent visual symptomology until the vision returns to normal (Kapoor and Ciuffreda, 2002).

The King- Devick Test (KDT) (Figure 2.3) does not require professional qualifications to administer making the test the optimum tool for any researcher to use (Leong et al., 2014). The test is on a laptop tablet base that takes around two or three minutes to perform plus time for instruction and reading, making it very easy to administer and not time-consuming. The test detects impairment of eye movements, attention span, language and other elements of suboptimal brain function. Within a meta-analysis including 1400 subjects, the KDT was both sensitive and specific for concussed patients. It has also been validated within other sports such as Rugby Union where the KDT identified unseen concussion at 6 times the rate of witnessed concussion (King et al., 2015). The need for a fast and efficient immediate post-concussion test is highly apparent as the most common used test is the Impact test which is a computerised test with varying levels of test and retest reliability. The test is also computer based and leads to issues for athletes due to the time-consuming processes. Recently within a study investigating the psychometric qualities it was found that out of the 300 report scores a total of 92 test score reports met inclusive criteria showing worrying figures in regard to reliabilities, ranging from 0.42 to 0.69 for composite scores and 0.19 to 0.71 for subscales comprising the verbal and visual memory composites (Gaudet et al., 2020). Therefore, Impact due to its inconvenient nature and unreliability is simply only a steppingstone to getting to a reliable and easy to use concussion baseline testing and immediate post-concussion tool.

The KDT (Figure 2.3) captures impairments of eye movement, attention span, and language which correlate to suboptimal brain function after a concussion. Due to its ease to use and easily transportable nature on an electronic tablet, it has been used in the literature in touch line testing within sports settings and within Mixed Martial Arts (MMA) (Galetta et al., 2011). The KDT was administered prefight and post-fight to 39 athletes. Results showed a significant difference in scores between prefight baseline score and post-fight scores (59.1 ± 7.4 vs 41.0 ± 6.7 seconds, $p < 0.0001$, Wilcoxon rank-sum test) and those with loss of consciousness showed an even greater significant difference between prefight baseline scores and post-fight scores ($rs = -0.79$, $p = 0.0001$) and a greater worsening of scores ($rs = 0.90$, $p < 0.0001$). Worsening MMA fighters with TBI scores were >5 seconds slower showing a further significant difference (Galletta et al., 2011). The literature shows that the KDT is a strong and a reliable testing method for identifying TBI.

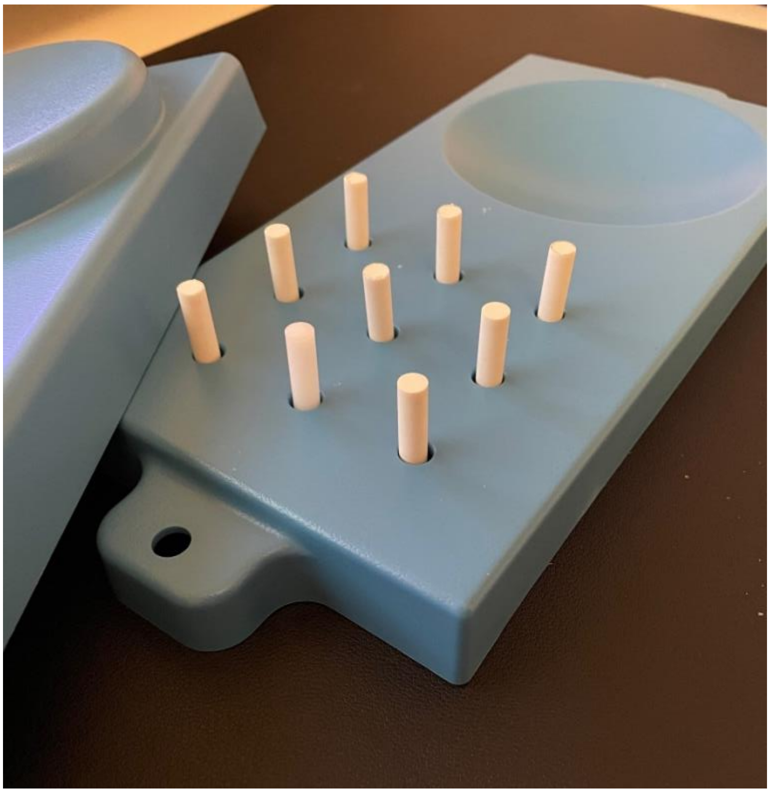
Figure 2.3 King Devick Test



The 9 Hole Peg Test (9HPT) (Figure 2.4) has not been used specifically in relation to concussion but is used frequently in the assessment or reassessment of multiple sclerosis, stroke, muscular dystrophy and Parkinson's disease (Earhart et al., 2011). It has reliability across those conditions as seen within Earhart et al., (2011) study of 826 students showing high test and retest reliability ($rs = .81$ and $.79$) and high interrater agreement ($rs > .99$). The test requires the subject to remove the pegs one at a time from a pegboard and then replace

them one at a time as fast as possible. It tests dexterity, coordination and cognitive functioning and this should allow the 9HPT to also have transferable reliability for concussion. It is a cheap test, quick, non-invasive and would have mass marketability if proven to be reliable.

Fig 2.4 The 9 Hole Peg Test



There are other alternative methods to baseline testing to diagnose concussive episodes, recently a study conducted into 1028 male athletes demonstrated the use of saliva and the role of MicroRNAs to diagnose a concussion (Di Pietro et al.,2021). The methods of collecting saliva were conducted using PCR tests over 2017-2019 with the head injury assessment used to also validate a concussive episode. The head injury assessment confirmed concussion in 106 players with high predictive accuracy found post game (AUC 0.96, 95% CI 0.92 to 1 post-game and AUC 0.93, 95% CI 0.86 to 1 at 36–48 hours) this non-invasive method identified unique signatures of concussion in saliva of male athletes. This study really shows that a quick and easy method to diagnosing concussion may be produced in the future, however, the cost of PCR tests, and their reliability is questionable as is a one-use case for each test. This will have an impact on accessibility to the wider population due to cost and environmental factors due to the amount of waste in one study alone (roughly 1028 tests used and thrown away) this on a mass scale is detrimental to the environment. Furthermore, with limited data for female and varying age groups, further research is needed with alternative methods that are more environmentally friendly and accessible to all.

Baseline tests can be impacted in many ways, therefore a robust methodology is key. within research conducted by Harper et al., (2021) which aimed to investigate whether a disabled athlete disability and concussion history impacted scores on baseline testing. Results showed that standardised assessments of concussion and the athletes wheelchair error scoring system used, were not affected by the athlete's disability or concussion history. Baseline testing was seen to be integral for disabled athletes, especially with underlying brain disorders and history of concussion. It shows that with a robust methodology and consistent approach baseline testing should be used for everyone no matter age, sex or disability (Harper et al., 2021).

2.14 Knowledge, understanding and attitudes towards concussion

Knowledge and attitude of an injury can define how fast someone recovers or how they react mentally to a setback, can determine how they apply themselves to the recovery process. With very little understood about concussion in the literature and the subject still only in its infancy, gaining a good level of understanding of the knowledge and attitudes towards the subject may be useful and has been seen in many other sports such as NFL, English Football and Cycling (Gallagher and Falvey, 2017; Rosenbaum and Arnett 2010 and Hurst et al., 2019).

A questionnaire can be used to find out any previous education, knowledge and understanding of the athletes and will thus gauge their awareness and attitudes towards a concussion. The RoCKSA-ST Concussion Attitudes Questionnaire is a useful tool (Rosenbaum and Arnett 2010). The questionnaire contains 25-items, a concussion knowledge index and a 15-item attitudes towards concussion index. The knowledge index has a reliability of 0.67 and the attitudes index has a reliability of 0.79 (Rosenbaum and Arnett 2010). The questionnaire will take approximately 10 minutes.

A research study conducted by Lee et al., (2016) into sports-related concussions (SRCs) in South Korea college athletes from a variety of sports tested knowledge and attitudes towards concussion. The study found that out of 410 athletes, none identified the correct signs and symptoms. However, 8.9% reported a history of concussion and approximately 50% of those had never reported their post-concussion signs and symptoms with 69% making their own return to play rehabilitation. These results show a lack of knowledge of the signs and symptoms of concussion, and the worrying statistic that over half of the young athletes decided themselves when it was best to return to playing sports. Throughout the literature, we know of the danger of Sudden Impact Syndrome (SIS) and the long-term consequences of concussion, yet young athletes are still lacking understanding of the methodological processes that need to be completed before returning to play.

English football hasn't been perceived in the past as a sport that would get concussions and misconceptions from managers, coaches and players are something that could potentially lead to concussive episodes being missed (Williams et al., 2016). Williams and colleagues used the Rosenbaum Concussion Knowledge and Attitudes Survey (RoCKSA-ST) together with a semi-structured interview of 26 professional Football players. Results showed a mean score of knowledge of 16.4 ± 2.9 (range 11–22) and an attitude score of 59.6 ± 8.5 (range 41–71). The interviews showed misunderstanding and barriers to reporting concussions. This could be due to lack of understanding and knowledge, but Williams et al. (2016) showed that Championship level English footballers have a moderate knowledge of concussion, safe attitudes and good concussion symptom recognition.

Mental toughness is a key element within an elite sports environment and has been heavily linked with success and good problem coping strategies (Nicholls et al., 2008). If mental toughness gives an individual resilience and confidence that may predict success in sport, then education in the workplace is essential (Jones et al., 2007).

The growth in the media influences and places additional stress and anxiety and in extreme cases induces suicide on elite athletes (Webner and Grant, 2016). A significant link between concussion and depression was found by Guskiewicz et al., (2007) after a general health questionnaire administered to 758 (with an age range of 50 years and older) retired professional NFL players. This revealed that 11.1% of all respondents reported prior clinical depression. Those players with a history of 1 or 2 previous concussions (36.3%) were 1.5 times more likely to end up with depression. Sports-related concussion is also associated with elevated levels of anxiety within athletes (Carlson et al., 2020). Therefore, an understanding of an athlete's mental toughness and anxiety could be key to a more detailed correlation between future depression, and worst-case suicide. Allowing athletes to have a better knowledge of this might allow them to self-diagnose and be more likely to seek professional help.

The 'Mental Toughness and Anxiety' questionnaire (MTAQ) is an 18-item self-reporting questionnaire (Clough et al., 2002). This questionnaire will delve into the athletes' mental toughness levels and a score out of 90 is given. A score of less than 57 may be an indication of low mental toughness and the athletes can be flagged for further assessment to their club physicians or even a local GP. This questionnaire could be a vital part in future research to enable a more in-depth understanding of athletes' "Mental Toughness".

There are few reported studies conducting research into knowledge, understanding, attitude and mental toughness within sports (Lee et al., 2016). The questionnaires in this study could potentially lead to further investigations into more in depth understanding of concussion and also raise awareness of concussion and thus to improve detection of early signs and symptoms and help toward an increase in self-diagnosis of amongst athletes.

CHAPTER 3. A Review of Maxillofacial Injury, Helmet strikes and Concussion.

3.0 Introduction

The aim of this study is to explore the context of cricket in more detail, whilst examining the number of maxillofacial injuries and concussion within professional cricket. The aim in gaining a more in depth understanding of the levels of maxillofacial injury and concussion was to direct whether there was a high level of risk within the ECB and the professional game. The chief medical officer and head researcher discussed the need to have insight due to the duty of care needed within the game. This kind of understanding had never been conducted prior to this study and therefore would only serve to benefit the entire ECB. Through a better understanding around the three areas, it would also guide future research into helmet design to protect future players. This was also discussed with the manufacturer of cricket helmets Masuri, the researcher, supervisor, and chief medical officer to see if the research would add value, it was concluded it would. The objective of reviewing the past amounts of maxillofacial injury and concussions within professional cricket will lay the foundation and direction of this research project from a high-level understanding of the rates and injured areas impacted due to ball impacts. As stated throughout the literature review, medical practitioners are very good at dealing with the traumatic site such as a laceration however, are we dealing with the concussive episodes asssociated?

3.1 Methodology and Materials

Medical staff throughout English County Cricket Clubs were invited to the ECB National Medical Conference by the Chief medical officer. On the day the lead researcher presented the need to investigate the levels of concussion and maxillofacial injury within professional cricket in order to direct and understand how serious and concerning the issues are for the county cricket players. This was to enable the medical teams to see value in the wider picture of baseline testing for improving the detection, education, and management of concussion. The rational was explained along with the protocols and information about the study procedures. Data was collated by the ECB through an internal data base called the Cricket squad and all athletes were recruited and assessed non-invasively. All data collected was anonymised through the ECB's online medical records databank. Each medial practitioner has a duty of care to the players to keep all medical notes and injuries up to date this is then logged internally at the ECB cricket. County Cricket Club doctors must record any injury through a central database that directly links to the ECBs medical records. Video evidence of the incident will accompany any medical notes at the time of examination as well as medical notes of injury outcome. All data is then collected and anonymised throughout cricket season. Data was sorted and intra and inter reliability checks were conducted by the head researchers.

On baseline testing day written consent form in accord with the International Conference on Harmonisation (ICH) and Good Clinical Practice (GCP) was circulated for athletes to read and sign. This was accompanied by an in-depth PDF document explaining each step of the baseline testing procedures for all participant to read through in their own time to make sure all information was transparent. On baseline testing day, and once the county medical staff were satisfied with the planned procedures, the Chief Investigator explained to the athletes what their participation involved and how the SCAT and other baseline tests would be conducted at the start of the meeting to make sure all participants are aware and happy with the flow of the testing this enabled a smooth and easy transition between groups. Throughout the baseline testing day participants were split up into groups of 5/6 participants to enable an easy and manageable group size for the researchers to maximise athlete's time. The lead researcher divided the groups up and explained the flow of the stations for baseline testing, so everyone understood which station to rotate to next to ease any wait time for the athletes. Regular communication was upheld between the lead researcher and the lead medical practitioners at each ground to accommodate the changing schedules of players during a preseason period.

The SCAT test was conducted in a quiet and private environment to allow all participants to concentrate and to try and standardise all results. The SCAT test is administered by the research. The test cannot be performed correctly in less than 10 minutes therefore a 20-minute window was given for all participant to administer the test that consists of immediate/on-field assessment, office/off-field assessment, student-athlete background, Glasgow Coma Scale, self-reported symptom evaluation, cognitive and neurological screening, and a balance measure.

All assessments were conducted by a team ranging in experience from General Medical Practitioners, Hospital Consultants, ECB employees, University PhD students, Research Fellows or Research Assistants. Standardisation of the SCAT test and teaching took place throughout the research project and before each baseline screening day, so the assessors minimized inter-examiner error this was conducted by the lead research in the ECB headquarters or onsite at the county cricket grounds. Baseline testing took place over a one to two-day period at each individual County Cricket Club ground. All assessments were carried out under strict confidentiality.

During the 2016-2018 season data was collected and then divided into varying categories for maxillofacial injury and concussive episodes. For reliability and GDPR an internal ECB staff member anonymised all data prior to the sharing of injury rates, this was shared through a secure sharing platform which was password protected. Data was analysed by a data scientist and inter and intra reliability checks conducted.

Recordings of the injury rates, site of injury, pathology and classification were obtained through medical records kept by each county cricket team, this proved to be very time efficient, and data was formatted through CSV download from the Cricket Squad secure platform into an excel spread sheets where sums, counts, standard deviation, averages, max, percentages and P values were analysed. The benefits to each County Cricket Club were discussed, together with an explanation of the English Cricket Boards (ECB's) duty of care towards their players, this showed the true benefit to the players welfare and also to allow medical practitioners to not only evaluate things through a subjective view over a three year period but also add a layer of objectivity to the data sets to try and understand the rates of concussion and if this topical area could be an area of concern.

The data collected was over 3 English cricket seasons (2016-2018) during both the pre-season and the playing season in each year. With the level of recordings of concussion lower from 2016 it would be beneficial in the future to have a longitudinal view of injuries to allow a more in depth understanding of helmet strikes, injuries, and concussion to occur. A total of 18 First Class professional cricket counties took part in this review. A total of 655 professional athletes played during the three seasons. Each athlete had to obtain a pre-season baseline SCAT test in order to determine whether during the season, and after another SCAT, a concussive episode had occurred post maxillofacial injury or helmet strike, this was all done to validate if a concussive episode had occurred. The SCAT test has previously been described in section 2.9.

The methods used to obtain the Maxillofacial injury rates and concussion rates throughout a three-year period were a very conventional approach. The data base has a systemised approach to collecting data to enable good quality data ingestion to minimise error occurring, however, mis diagnosis will not recognise concussion therefore the SCAT test is key to determining rates. Helmet strike definition also needs to be questioned as subject-to-subject definition may vary in defining a helmet strike or a glancing blow.

The reality of a sporting environment, having played professional sports myself, is very multifaceted and complex, with schedules and timing affecting processes. Therefore, a recognised way of determining a concussion, implementing baseline testing and accommodating a preseason schedule is very challenging and a streamlined approach to collecting the data through a cricket squad database is required which can then be used to evaluate the data sets in the most efficient and non-time-consuming process for the professional teams. With many different baseline tests used and the outcome clear from the ECB of determining maxillofacial injuries and concussive episodes, the methodology was the cleanest and most time efficient to gaining some answers to the question posed by the ECB and allows the foundation for future longitudinal research into helmet strikes, concussion rates and maxillofacial injuries.

3.2 Results

Year	Maxillofacial injury
2016	5
2017	5
2018	11
TOTAL	**21**
AVERAGE	**10.5**

The total recorded maxillofacial injuries in professional cricket during 2016-2018 seasons and the average are shown in **Table 3.1**

Injury reported	Total
Laceration	8
Haematoma/bruising	13
Total	**21**

Table 3.2. Total number of lacerations, Haematoma, and bruising

Area of Maxillofacial injury	**Number**
Nose	1
Eye/Eyebrow	2
Mouth	3
Jaw	6
Scalp	9
Total	**21**

Table 3.3. Area of maxillofacial injured and total number

Maxillofacial Injuries 2016-2018	**Number**	**% of total**
Nose laceration	1	5%
Scalp bruising/ Haematoma	6	29%
Scalp laceration	1	5%
Head/Facial Bruising/Haematoma	2	10%
Lip laceration/abrasion	2	10%
Jaw Laceration	3	14%
Jaw Bruising/Haematoma	4	19%
Eye bruising/ haematoma	1	5%
Eye laceration/abrasion	1	5%
TOTAL	**21**	100%

Table 3.4. Number of Maxillofacial injuries and type during 2016-2018 and % of total

Year	Maxillofacial injuries	Concussions and Maxillofacial injuries	Days missed
2016	5	1	22
2017	5	0	6
2018	11	0	1
Total	**21**	**1**	**29**

Table 3.5. Number of Maxillofacial injuries, concussions, maxillofacial injuries and days missed from players due to injuries

3.3 Discussion

An understanding of maxillofacial injuries within sport is important in developing safety initiatives. To address these, it is critical to understand the levels of injuries occurring over a time frame. Over the three-year period of this study between 2016- 2018 Table 3.1 shows there were 21 maxillofacial injuries recorded with an average of 10.5 per season which demonstrates a lower injury rate when compared to the subject pool of 655 athletes. In the year of 2018, it was seen to have the highest maxillofacial injury rate of 11, this may be due to a level of awareness around injuries becoming higher throughout the ECB and education around injury year on year. The highest level of injury reported was Haematoma/bruising, 13 of the 21 reported with 8 lacerations this may be due to the protective helmet used during cricket, however, the scalp was seen to be the most common area and nose least with 1. This is difficult to draw any real conclusion from due to the low levels of incidences, further longitudinal data analysis would be beneficial in enabling a more detailed understanding of maxillofacial injuries within professional cricket. With 29% of total injuries coming from scalp bruising/ Haematoma other sports may also have similar rates. Within a study into maxillofacial injuries within ice hockey, over a 9-year period lacerations were the most common injury type 43.1% Cohn et al., (2021) which is not in coordination with the findings in cricket. Only 1 concussion was recorded in 2016 that was linked to maxillofacial injury, but 22 days were to injuries of the total 29 days missed by athletes. Days missed from training and match play is never beneficial for the athlete or business. If the best athletes are not participating in matches it is more than likely that teams will lose matches which impacts financial growth for a business. For the athletes themselves psychological demands of sport is higher than ever due to the impact of social media. With injuries often the topical area and fans with access to comment on personal profiles the impact could be even greater on their mental health. Financial impacts are often high due to injury clauses in contracts and early release clauses when players are unable to return from injuries such as concussion. With teams holding athletes' careers and health in their hands and the power to release players early due to injuries caused doing their job, they really do have a duty of care to look after the athlete's health not only in the short term but also in the long term and for later life if having to retire early.

3.4 Conclusion

The rates of maxillofacial injury within professional cricket are low. This may be due to mandatory intervention after the death of professional cricketer Phillip Hughes in 2014. However, with Scalp bruising/ Haematoma accounting for 29% of all injuries in this study, we feel that helmet design may benefit from future and more in-depth research, in particular into the different materials used in helmets for other sports. Research has shown that at a 27m/s impact speed, certain cricket helmets have insufficient protection when compared to ice hockey and baseball helmets (Mclntosh and Janada, 2003).

Aspiring to improve the quality of protective equipment can only be beneficial in preventing maxillofacial injuries within cricketers as limiting injuries to keep athletes available as much as possible is only beneficial. Even though rates are low of maxillofacial injuries within cricket that is only a conclusion over a 3-year period, a more longitudinal approach is needed within future research. However, it is clear to see injuries occurring and therefore anything to de-risk a sport and improve player welfare is warranted. For a concussion to occur it does not have to be linked with a maxillofacial injury as shown with only 1 linked within the study, however, that does not mean that increased exposure to helmet impact does not increase your risk of a concussive episode. Further investigation into helmet strikes and concussion is also needed as symptomology does not need to be visible for a concussion to have occurred. With an increase in reporting of maxillofacial injuries seen between 2016-2018 this may be down to the education in and around concussion injuries, and baseline testing may of subconsciously intervened with practitioners to report injuries more often and in a more detailed manner hence the increase in reporting giving a truer indication on the prevalence in cricket.

Chapter 4. Analysing Helmet Strikes and Concussion in Professional Cricket

4.0 Introduction

The definition and identification of concussion has no universal accepted definition however, one of the most popular is “a trauma induced alteration in mental status that may or may not be accompanied by a loss of consciousness” (Collins et al., 1999). Unfortunately, sports players across the world at all levels incur injuries when participating in contact and non-contact sports. It has always been long been known that contact sports such as American football, Rugby Union and Rugby League have carried risks of concussion and injury which has been shown through research over many years. There is very little literature about concussion in cricket.

Clinical evaluation of a concussive event relies on many different information sources; trainers, coaches, collision witnesses, data from instruments and the victim's own reports of symptoms, these all combining to make concussion very difficult to diagnose Budinger (2016) the signs and symptoms of concussion can vary from episode to episode and patient to patient. Diagnosis of concussion currently relies on multiple clinical "symptoms and signs" these are**: Cognitive:** concentration, memory, information processing, executive function. **Motor:** reaction time, coordination. **Vestibular:** balance, dizziness, vision/ oculomotor function and **Physical:** headache, neck pain, sleep disturbance.

Many misconceptions about concussion still exist; needing to have been "knocked unconscious" for a concussion to have occurred is probably the commonest myth and wearing protective equipment "can stop all concussions and head injury occurring" is another. These misconceptions highlight the need for education about concussion to enable a true deeper understanding of what it is, how to diagnose it correctly and also how to potentially improve treatment and rehabilitation around it (Valovich et al., 2007). Firstly however, gaining an understanding around injury types within professional cricket is key to mitigating risk within the sport and therefore gaining a better understanding of injuries around the cranium and face caused through incidences like helmet strikes, which could lead to a reduction in injuries within the sport at all levels. Mitigating all risk within sport might be difficult, but through research and innovation the hope must be to understand in depth what injuries are occurring and how we can avoid putting athletes at unnecessary risk through better technology and equipment whilst improving the care and rehabilitation if injury is to occur.

American Football has shown that wearing a protective helmet does not prevent concussion (Bartsch et al., 2012). This is because the impact and biomechanical forces resulting from an external impact are carried through the helmet and cranium to the cerebral tissue. There are multiple different interrelationships among the forces produced during a head impact or sudden head and neck movements with each TBI varying and the biological response of the body may be delayed or immediate (Mourouzis and Koumoura 2005). Two specific changes occur in an TBI: structural (torn vessels and axons) and functional (changes in blood flow or neurological status).

An investigation and understanding of helmet strike and the rates of concussion in cricket will help to clarify the severity of these issues and inform a better and improved duty of care towards the athletes themselves. Improved knowledge of the rates of helmet strikes and concussive episodes might lead to an improved cricket helmet design, thus reducing the risk of concussion when playing cricket. By investigating maxillofacial injury, alone we would never get an understanding of the injuries that “we can’t see” through the naked eye such as concussion. As we are aware through previous research you don’t have to have a visible maxillofacial injury or be rendered unconscious for concussion to occur.

4.1 Methodology and Materials

Information about Helmet Strikes and Concussion were obtained from the data base linked to ECB Medical records (Section 3.1). All methods and materials collected are stated in (Section 3.1).

4.2 Results

The total number of helmet strikes, the number of concussions arising from those strikes and the concussion rate (helmet strike: concussion ratio) are shown in Table 6.1.

In the three seasons 2016-2018 there were 155 helmet strikes, 47 concussions arising from these, and a mean concussion rate per helmet strike of 30%. The concussion rate from helmet strikes fell in successive years 2016-2018 (Figure 4.2.)

Table 4.1. Helmet strikes, Confirmed Concussions from Helmet strikes and Concussion Rate for years 2016, 2017, 2018.

	Helmet strike	**Concussion from HS**	**Concussion Rate**
2016	23	11	48%
2017	38	12	32%
2018	94	24	26%
TOTAL	155	47	Mean 30%

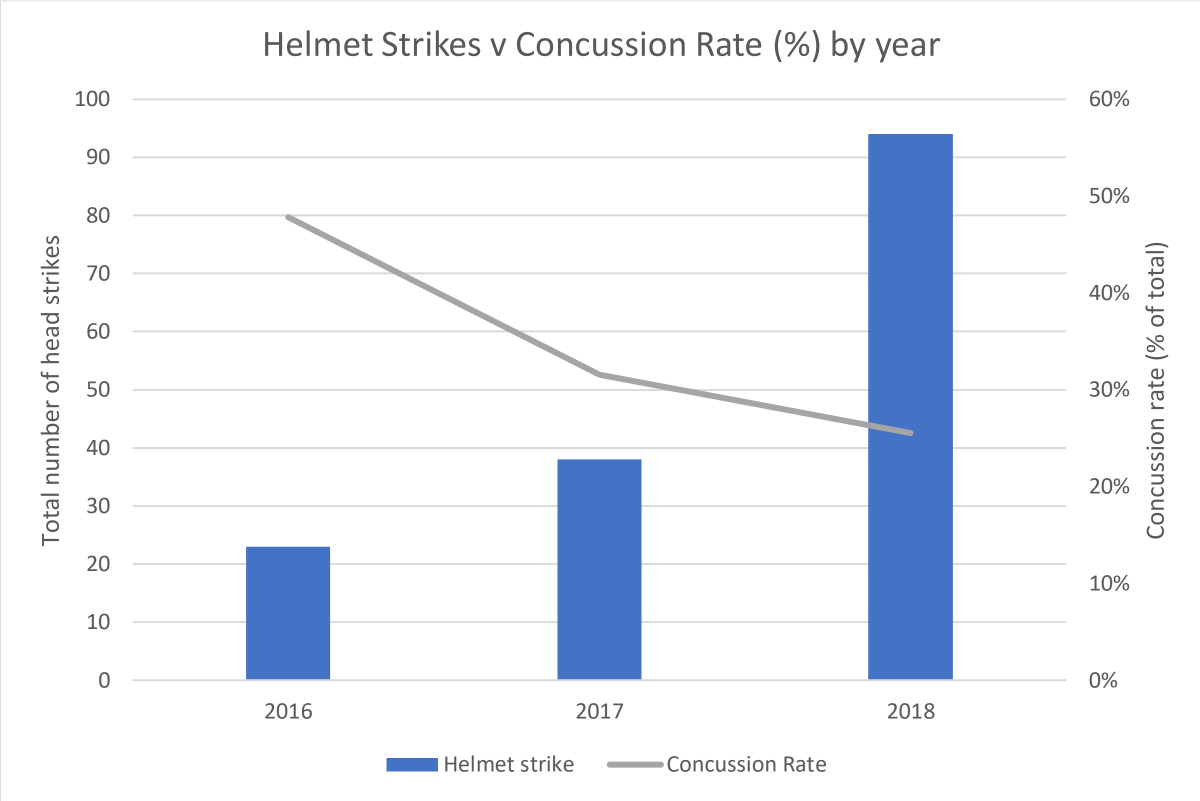
Table 4.2. Helmet strikes, Concussion, Concussion Replacement, mean days missed per player, Helmet Strike: Concussion ratio.

Helmet strike	**Concussion**	**Concussion Replacement**	**Total Days Missed**	**Mean Days Missed per player**	**Helmet Strike: Concussion Ratio**
155	47	9	347	7.4	3:1

The 47 concussions arising from the 155 helmet strikes resulted in 9 players having to leave the field of play, 347 total playing days lost whilst players were undergoing rehabilitation and a mean of 7.4 days lost per player (Table 4.2.)

Figure 4.1. Helmet Strikes by Location (site) 2016, 2017, 2018

Figure 4.2. Helmet Strikes versus Concussion Rate (%) 2016, 2017, 2018.



The relationship of helmet strikes to type of match played is shown in Table 4.3. The different types of matches have different durations. Most helmet strikes were recorded in 4-day matches (52), however the one day 50 over and 20/20 matches sustained 20 and 17 helmet strikes respectively.

Table 4.3. Type of match versus Helmet Strikes 2016, 2017, 2018.

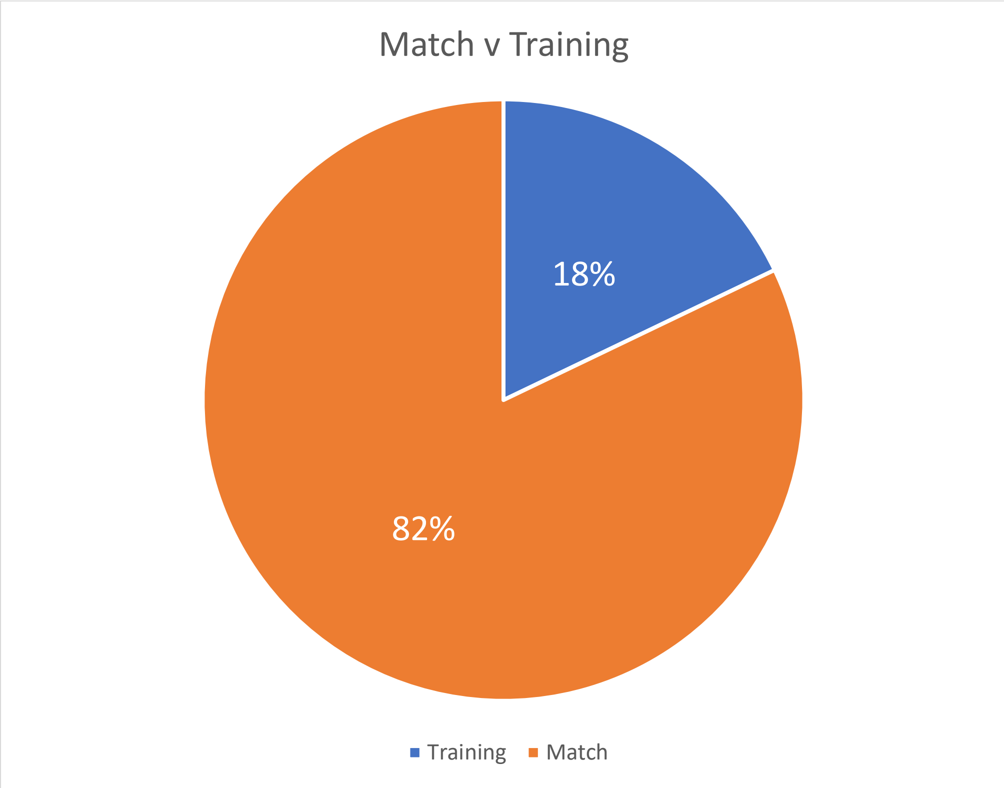
Type of Match	Helmet Strikes
Training	30
2nd XI	30
20/20	17
50 overs	20
4 days	52
Test Match	4
Other	2

The number of helmet strikes in different playing situations are shown in Table 4.4 and Figure 4.4

Table 4.4. Playing situation versus Helmet Strikes 2016, 2017, 2018

Playing Situation	Helmet Strikes
Training	27
Match	124
Other	4

Figure 4.3. Match versus Training for Helmet strikes (%)



The number of helmet strikes by Match and Training are shown in Table 4.5 between 2016-2018, and by playing level are shown in Table 4.6.

Table 4.5. Match versus Training for Helmet Strikes by years 2016, 2017, 2018.

Playing situation	2016	2017	2018
Match	29	41	94
Training	17	18	26

Table 4.6. Playing level and Helmet strikes.

Playing Level	Helmet Strikes
Academy	9
2nd XI	15
1st XI	117
International	12
Other	2

4.3 Discussion

The overall number of helmet strikes for years 2016, 2017 and 2018 was 155 with 47 of the helmet strikes leading to a concussive episode equal to 30% of all helmet strikes. In the 2016 season there were 23 helmet strikes and 11 concussions: the highest concussion rate (48%) of the three-year period. This shows a higher rate of helmet strikes compared to maxillofacial injuries over the same time suggesting a stronger link between helmet strikes and concussion occurring.

As a result of the tragic death of Philip Hughes in Australia in 2014 the 2016 agreement between UCLAN University and the ECB set out to establish: "**Analysis of baseline testing for improving the detection, education, and management of concussion".** The baseline testing intervention appears to have had an impact with a potential increase of awareness, demonstrated by an increase in the surveillance of helmet strike data and a decrease in concussive episodes. In 2016 there were 23 helmet strikes, 11 concussions and a 48%

concussion rate; 2017 showed 38 helmet strikes, 12 concussions and a 32% concussion rate; and in 2018 there were 94 helmet strikes, 24 concussions and a 26% concussion rate. A systematic review of 23 articles and meta-analyses of studies assessed the incidence of concussion of 1000 athletes involved in a variety of sports: American football; Soccer; Basketball; Baseball; Softball; Wrestling; Field Hockey; Track Taekwondo; Volleyball; and Cheerleading. The three sports with the highest rates of concussion were: Rugby Union 41.8%; Hockey 12%; and American football 53% (Pfister *et al.,* 2015). The lowest rates occurred in Volleyball 3%, Baseball 6% and Cheerleading 7%. The context of number must be factored into any analysis and comparison of results, however, there are striking differences found between all sports suggesting that testing, diagnosing and rehabilitation must be individualised and contextualised to the specific sports being played. Furthermore, it is important for all sports to be able to diagnose a concussion correctly, primarily for the well-being of the participants but secondarily to collect accurate and appropriate data,

Since sports turned professional, the sporting industry has grown across the world into a multi-billion-pound industry and athletes, through sponsorship and increasing wages can be earning lucrative sums of money, Therefore, many teams want to get the most out of their biggest assets and missing game time due to injury is not ideal. Within this study it has been reported that the total days missed through a concussion or Helmet strike in professional cricket during the years 2016-2018 covering three playing seasons was 347 days, with a mean of 7.4 playing days lost by each concussed athlete. This shows that Professional Cricketers could miss nearly two 4 day matches or over a week of training. Unfortunately, other injuries also occur throughout a professional sports person's career; 23% of 158 professional Cricketers reported shoulder injuries in the 2005 season alone (Ranson and Gregory 2008), leading to individuals playing through injuries or playing with compromised fitness, suffering in silence, due to concerns of not being selected or dropped. There is a need for the development of a data collection system for national cricket injuries and prevention to help to predict, reduce and prevent injuries at all levels of cricket (Leary and White 2000).

The understanding of the biomechanical forces that penetrate cerebral tissues that can lead to disturbances to normal brain function is key in understanding the location of a concussion. If we are able to indicate the amount of helmet strikes, the number of concussive episodes and the number of maxillofacial injuries in professional cricket it will enable us to have a better understanding of the rates and risk to players. The location of helmet strikes will aid in potential future improved helmet design and manufacturing to add protection to players. This was seen in 2015 when Kumar Sangakkara the then Sri Lankan captain and currently president of the MCC (Marylebone Cricket Club) was the first player to wear the StemGuard for posterior protection after the death of Philip Hughes. Review of the results between 2016-2018 in this thesis show that of the 155 helmet strikes recorded, some 133 strikes occurred Anteriorly, 21 Posteriorly and with 1 unknown location. The findings show that most impact occurs at the front of the helmet, left or right side, this may be due to the positioning of the player when facing a high-speed ball and a reaction to run away. Further investigation into helmet design and the biomechanical forces absorbed and translated through the helmet to the skull would help to gain a better understanding of the speed, angles, weather type and cricket ball age in relation to concussion injuries. Head kinematic data can show in depth aspects of internal forces allowing helmet design to accommodate for rotational forces. External factors such as snow have been shown to be important in the Super-G helmet design for skiing (Kleiven and Halldin 2013).

Injury can occur at any point throughout training, match play or everyday life. Within the study match length and type was analysed and investigated to obtain the source and likelihood of a helmet strike. The highest amount of helmet strikes (52) occurred during the 4 day matches. This may be due to the fatigue that may occur to a player during the long-repeated days and the direct link between fatigue and underperformance (Budgett, 1998). Players within professional cricket may not get the chance to face many cricket balls whilst batting depending on their batting position and match length, therefore, the assumption may be that helmet strikes during training would be of a similar number. However, a total of 30 helmet strikes were recorded during 2016-2018 training sessions and a total of 125 during match play were recorded showing a 125-incident difference, with the lowest seen in a test match scenario (4 helmet strikes). This could be due to under reporting in training due to lack of video evidence, therefore making recording mandatory in training sessions may help to gain a better level of understanding. With 1st XI players, the highest rate of helmet strikes was 117, however, the majority of players within the study are 1st class players so a deeper and wider understanding is needed at all levels of professional cricket.

4.4 Conclusion

The data and statistics regarding concussion widely vary. However, it is estimated that approximately 300,000 sports related concussions occur annually within the US alone (Bartsch et al., 2012). This shows the need for greater participant welfare through more research to gain a deeper understanding of levels and rates that may lead to a concussive episode.

Throughout the study a rise in awareness of potential concussive episodes throughout cricket showed an increase in helmet strikes between years 2016 and 2017 and between 2016 and 2018. However, a decrease in concussive episodes was seen across all years, showing that better awareness and better potential diagnosis of concussion was achieved. The highest rates of concussion occur on a 4-day, 1st XI matches with minimum occurring within training sessions.

Most helmet impacts occurred anterior left- and right-hand side, therefore suggesting further research may be conducted into helmet design and strengthening in certain areas. Further research would also be beneficial into the forces absorbed from a helmet strike into the cranium allowing for the development of better equipment and materials to reduce concussion within cricket.

With many instances between 2016-2018 of maxillofacial injuries (21) helmet strikes (155) and concussions (47) there is a real need within professional cricket to support the detection of concussion and educate players and staff around the topical area. All county cricket clubs would benefit from this as 29 days were lost to maxillofacial injuries and 347 days missed from concussion. This would impact so many varying aspects involved including players' mental health, county clubs losing money, potentially loosing stat players, and loosing matches. International players would also miss the opportunity to play for England due to concussion. With better levels of education, baseline testing and analysis around concussion it could impact the sport in only a positive manner.

Chapter 5. Baseline Testing in First-Class County Cricket players: a pilot study

5.0 Introduction

The terms concussion and traumatic brain injury (TBI) have become increasingly common and in contact sports such as Rugby Union and American Football, it is common to see at least one concussive episode per game. However, non-contact sports such as Cricket don't avoid these injuries, and when Philp Hughes died in 2014 an investigation started into concussion rates and testing in worldwide cricket. Between 1870 and 2015 only 36 events of head injuries in cricket were recorded Tripathi et al., (2015). Compare this to Hill et al., (2018) who reported 92 head impacts alone in a 2-year period. This suggests no standardisation of reporting and possibly a lack of knowledge and understanding of concussion.

Rates of concussion within contact sports such as American football, Rugby League, Ice Hockey and Rugby Union are better documented in the literature. In New Zealand, Rugby Union is the most popular sport in the country, and it accounts for up to 50% of all Maxillofacial injuries (Lee, 2008).

The lack of diagnostic tools makes concussion diagnosis more challenging. Researchers are continually striving to develop tools but no one singular test has yet been able to incorporate all the multidimensional facets associated with a TBI. Baseline testing has been shown in the literature to have a positive impact when nursing return athletes back to full fitness and preventing future injury (REF). The overall surveillance of illness, injury and epidemiological studies are the foundations of protecting the health of athletes (Bahr et al., 2020).

The aim of the pilot study is to pilot the baseline testing procedures to enable a greater understanding of the levels of knowledge around the signs and symptoms of concussion and create a smooth and quality data collection method to occur throughout the research project whilst allowing the development of an educational process around concussion for all players and staff. With the objective of increasing the levels of education to improve diagnosing concussion correctly, the use of baseline testing is to obtain baseline scoring records to enable the management of the rehabilitation process to become more efficient, giving players a better level of duty of care across the whole of the ECB. The pilot study enabled all medical practitioners across all county cricket clubs to question the study before a mass roll out, gaining a need for a deeper understanding of the rates of concussion within professional cricket and the necessity to understand the levels of knowledge around concussion within professional cricket and the ECB. The pilot study would help shape and guide the following years research and provide a guide into areas of interest for future research.

5.1 Methodology and Materials

Medical staff from the English County Cricket Clubs were invited to participate in the study by telephone and email contact. During a meeting with the Chief Medical Officer of the England and Wales Cricket Board (ECB), Professor Nick Pierce, the study rationale was explained together with the protocols of the study procedures. The benefits to each County Cricket Club were discussed along with the ECB's duty of care towards their players. The chief investigator presented alongside the Chief Medical Officer at the annual medical conference for all county cricket clubs. Within the presentation all medical partitioners had the chance to discuss the pilot study and all future research of the study with the lead researcher.

Once confident that all medical staff were satisfied with the study procedures, Professor Pierce and the lead researcher discussed the roll out of the baseline testing days and how these would be conducted at each county cricket club.

At the visits to the clubs the chief investigator presented the different aspects of the study to the professional athletes involved in the pilot study prior to their baseline examinations. A written invitation to participate with a consent form was given to the athletes and subsequently signed in accord with the International Conference on Harmonisation (ICH) Good Clinical Practice (GCP). This documentation was accompanied by an in-depth PDF document explaining each step of the baseline testing procedures for the athletes to read through in their own time if needed.

The baseline screening tests involved four main areas which concussion is known to impair: balance; coordination; reduced speed of ocular processing and movement; cognition and recall (For a full description of the tests see Section 2.9). The baseline screening was accompanied by a concussion attitudes questionnaire. All screening assessments were carried out under strict confidentiality with all subjects providing basic demographic data including age, height, and nationality. Sports history was also taken and consisted of professional role, number of years playing professional cricket, total years playing cricket and number of concussions.

A General Health screening involving a cardiorespiratory examination of all participating athletes was performed by the Club Doctor including heart rate and blood pressure, had been completed prior to the study visit.

All the baseline study assessments were conducted by a team of volunteers ranging in experience from General Practitioners, Hospital Consultants, ECB employees, University PhD students, Research Fellows or Research Assistants. Standardisation of tests and teaching took place prior to each screening day to minimize inter-examiner error. All baseline testing took place over one day at the appropriate County Cricket Club ground. The testing procedures and expectations were spoken on, highlighted, and demonstrated before each participant to enable good and standardised delivery. Once a participant had finished a test they would rotate to another test until they had completed a full circuit and all tests were complete. This allowed for the most time efficient and systematic way of conducting the baseline testing. The chief researcher floated between stations to make sure all participants were happy with their next place and to decrease the possibility of participants leaving without completing the entire battery of tests.

The organisation of 18 County Cricket clubs could potentially hinder the smooth running of the project, therefore, the Chief Investigator obtained all contact details from the ECB and subsequently arranged dates and times to visit with travel times and schedules having to be aligned through email and phone calls. It was paramount that communication was upheld with all parties through the chief investigator. All tests were conducted within the athlete's offseason to try and give every player the opportunity to participate within the research project, this was key within professional cricket as many players live all over the world.

The Immediate post-concussion assessment and cognitive testing (ImPACT) (Resch et al., 2013) is a computerised neurocognitive test that is used for evaluating sports-related concussion with documented sensitivity and reliability (Kellor et al., 1971). The test lasts approximately thirty-five minutes. The Impact test is very useful whilst assessing an individual’s fitness for returning to play however, it will play no part in our study to due to it playing little role in diagnosis of concussion.

We will be using the following baseline tests which could be used pitch side as part of this research study.

The Head Injury Assessment (HIA) screening uses a SCAT (Sports Concussion Assessment Tool) test which is used in many sports as a baselining tool. It tests all four of the main brain functions impaired by concussion (McCrory et al., 2013). SCAT covers multiple brain functions superficially rather than in depth and therefore it is thought to be inadequate. This test was conducted in a quiet and private room so that participants could concentrate fully on the questions asked, as in all social environments, distractions could lead to mistakes in answering questions and reduce the accuracy of a baseline score. The SCAT test was conducted in paper form and then entered into a excel spread sheet to reduce the risk of any data getting lost if needed for comparing to previous scores. This was shared secularly with the county cricket club Head Medical Practitioner. This also allowed for easy transportation of participants baseline tests as county cricket teams travel to matches frequently.

The Single-Leg Balance Test (SLBT) was administered by the athlete balancing on one leg, hand on hips, with eyes closed. The test position was demonstrated to each athlete before their test and any athlete with lower limb injuries or disabilities was removed from the test. The test lasted twenty seconds and was repeated on each leg (Sambasivan et al 2015 and Teel et al., 2016). The test is extremely easy to conduct and very time effective.

The King- Devick Test (KDT) is on a laptop tablet base and took around two or three minutes to perform including time for instruction. The test consists of three test sheets with rows of numbers. The numbers on the test sheets get progressively closer together. The athlete reads the numbers on each sheet from left to right from the top to the bottom of the sheet as fast as possible with no mistakes made. If a mistake occurs and correction from the participant is fast, they can continue. If the participant does not correct the mistake they must start again. The total time for the three sheets is recorded in seconds.

The 9 Hole Peg Test (HPT) was demonstrated to each athlete prior to recording their times for four tests; two with the left hand and two with the right. Their handedness was noted for each athlete. The administrator on the test uses a stopwatch to record how fast each attempt had taken and was then written down on paper by pen. If a peg did not make the hole or landed on the table outside of the case, the administrator must put the peg back into the loading dish for the participant to continue the test. If a peg was unable to be retrieved then the test must be restarted.

The RoCKSA-ST concussion attitudes questionnaires was administered to the athletes to find out their previous education, knowledge and understanding of concussion (See Section 2.10). This took approximately 10 minutes to complete. The test was conducted in a quiet and exam like fashion with no conferring of questions and must be completed by an individual. Pens were provided to all participants to complete the questionnaire and all participants must sit 2m apart to decrease the risk of cheating.

Limitation on the baseline testing days came from external issues such as people becoming sick or unable to travel due to traffic. This did put pressure on the baseline testing day and all the other researchers. However, in the future taking one extra researcher if needed will be vital in allowing for these unpredictable issues. Furthermore, last minute changes to participant's schedules within the county cricket clubs for other meetings such as media must be equated for to allow participants to complete the full circuit of tests without breaking and coming back later in the day. This not only wastes time but could also impact results due to concentration levels needed for the baseline testing and fatigue at the end of a busy media day could impact this.

5.2 Results

57 professional male Cricketers from 4 different first-class County Cricket Clubs were baseline tested over 4 months between December 2016 and March 2017. Levels of ability within the study ranged from 2nd XI (2), 1st Class (37), England Lions (4), and International (14). All players were from Great Britain and Ireland except for two from Australia and one from New Zealand.

General demographic information is shown in Table 5.1. The mean age was 26.05 years with the oldest player 37 years and the youngest 17 years (STD 4.84) with an age range of 20 years. The mean height was 182.98cm with the tallest 207cm and the shortest 170cm (STD 8.18) and a range of 37cm. The mean number of years as a professional cricketer was 7.30 years with the longest-serving professional 19 years and the shortest only 1 year (STD 4.93) and a range of 18 years. Furthermore, years of playing all cricket gave a mean of 18.93 years with the longest playing time 31 years and the shortest 8 years (STD 5.69) with a range of 23 years.

This information shows that the participants have been involved in all forms of cricket and professional crickets for a significant amount of time. This might suggest a high level of education and mental toughness from playing a sport for so many years with 51 of 57 participants making it to first-class cricket or international level cricket.

Table 5.1 General demographic information for the athletes

Player ID	Height (cm)	Age	Number of Years as a Professional	Number of years playing Cricket total	Number of Concussions in Total
Mean	182.98	26.05	7.30	18.93	0.44
Highest	207	37	19	31	5
Lowest	170	17	1	8	0
STD*	8.18	4.84	4.93	5.69	1.04
Range	37	20	18	23	5

*Denotes Standard deviation

The mean number of concussions the participants had previously incurred was 0.44 (STD 1.0) with a range of 5.

Table 5.2 Playing roles of athletes.

Professional Role	Number
Batsman	15
Batsman / Wicket keeper	4
Wicket keeper	2
All Rounder	20
Bowler	17

The results for SLBT, KDT and 9HPTs are shown in Table 5.3

Table 5.3 Results for 9HPT, SLBT and KDT.

	9HPT RH1	9HPT RH2	9HPT LH1	9HPT LH2	SLBT R	SLBT L	KDT
Mean	18.54	18.09	18.93	18.48	15.69	18.32	38.5
Highest	36.4	41.6	22.6	24.5	36.5	41.6	51.7
Lowest	6.25	5.5	14.9	14.6	4	5	26.1
STD	4.24	5.5	1.84	2.02	8.29	9.04	5.72
Range	30.2	36.1	7.7	9.9	32.5	36.6	25.6

L – left, R -right, H – Hand. 1 – first attempt, 2 – second attempt left,

In the Single Leg Balance Test (SLBT) the right leg stance was weaker than left leg stance with an average 2.63s difference.

The King Devick Test (KDT) showed a mean score of 38.50s.

In the 9-hole peg test the mean scores for left and right hands were very similar, with less than 0.5 second difference (favouring the right hand) between the means of the two attempts for left and right hand.

The results for the RoCKSA-ST Concussion Attitude questionnaires are shown in Table 5.4.

Table 5.4. Results for ROCKSA-ST Concussion Awareness

	Concussion Attitude RoCKSA-ST Results
Mean	35.64/47
Highest	44/47
Lowest	19/47
STD	6.11
Range	25

The mean score for the RoCKSA-ST Concussion Attitudes questionnaire was 35.64. The maximum possible score was 47.

The Impact concussion screening test was online and cannot be reported. It is however a highly validated and proven tool and a valuable addition to the baseline testing armamentarium.

5.3 Discussion

Numbers of participants were small in the pilot study 57 but there was a suggestion that in a larger multicentre study we may be able to identify differences in baseline tests related to an athlete's skill – set for example the wicket keepers and the 9 hole peg test.

One significant statistic from the pilot was that only 1 of 57 participants correctly answered the question about the signs and symptoms of concussion in the RoCKSA-ST questionnaire. Even those who had a previous recorded concussion did not perform better at this question. This is indicating that there is a lack of knowledge and understanding around concussion and the signs and symptoms within 57 participants within the pilot study, however, it is too early to make any assumptions and conclusions.

Further education about the signs and symptoms of concussion must be at the forefront of this project and any such future projects if team members are to be able to recognise the signs of concussion in themselves or a colleague. If the education element of the study has a positive benefit it could be that more cases of concussion will be identified in the future, this would lead to earlier diagnosis management and reduce further damage such as second impact syndrome.

The highest score seen on the RoCKSA-ST was 44 out of a possible 47 and the lowest 19 showing a wide range in results a difference of 25 and a standard deviation of 6.11 it would suggest results are varied equalling to the wide range of understanding of concussions signs and varied symptoms. Following the wide range of scores on the RoCKSA-ST there was seen to also be a wide range of previous exposure to concussion with participants having as little 0 concussions up to other participants having 5 concussions. This may be due to playing other contact sports such as rugby union in the past prior to playing professional cricket.

Mean score for the 9-peg hole test are shown to be consistent across the 4 attempts on left and right hands 18.54, 18.09, 18.93 and 18.48 seconds suggesting that the sensitivity of this test maybe high and consistent for all participants. Even though the test has not been used within specific concussion baseline testing this test does demonstrate the need for great motor control which can be disturbed by a concussive episode.

5.4 Conclusion

The collection of data in the pilot study from the baseline tests of ImPACT, SCAT, SLBT, KDT, 9HPT and the Demographic, RoCKSA-ST questionnaire was possible with a small team of well trained and calibrated researchers. Organisation and planning were key elements, and it was deemed feasible to take this forward to a multicentre study.

The early results suggest limited levels of education around the signs and symptoms of concussion within professional cricket but with only 57 participants no true conclusions can be made. The pilot study was successful in gaining traction from all county cricket clubs and the ECB could make assumptions that the research project rolled out in an effective way would be success for all county's to take part, therefore Professor Nick Peirce made the research project open to all county cricket clubs with all 18 wanting to take part in the research project.

This would allow a much more detailed understanding of the levels of knowledge and understanding around concussion and the use of baseline testing as a tool within professional cricket. Due to the success of non-medical practitioners needing to administer the baseline test it was easier to recruit more researchers to help with the uplift of all 18 county's cricket clubs and build a more robust team around the original research team.

Chapter 6. Baseline Testing in Professional Cricketers: A multicentre study

6.0 Introduction

The aims of this multicentre retrospective observational cohort study was primarily to determine normative baseline values in Professional Cricketers and secondarily to ascertain whether there are different baseline scores for different professional roles (skill-sets). Furthermore, to understand the levels of knowledge around the area of concussion within professional cricket.

6.1 Methodology and Materials

Methodology and Materials please refer to (section 5.1).

6.2 Results

A total of 655 male Professional Cricketers were tested. Each athlete was categorised into Country of origin (see appendices 2); Highest level played: International; International A; 1st XI or 2nd XI; Professional role: Batsman, Batsman and Wicketkeeper, Wicketkeeper, All-rounder and Bowler. (Tables 6.1. and 6.2)

Statistics

An unequal variance t-test was conducted on data sets to interpret any P-value between baseline testing scores and playing positions ($P>0.05$).

Table 6.1. Playing levels achieved.

PLAYING LEVEL	**NUMBER**
International	131
International A	55
1^{st} XI	434
2^{nd} XI	34
TOTAL	654

1 unknown participant playing level

Table 6.2 Playing Role**s** of athletes

PROFESSIONAL ROLE	**NUMBER**
Batsman	160
Batsman/ Wicket Keeper	55
Wicket Keeper	12
All Rounder	215
Bowler	210
TOTAL	652

3 unknown participant playing roles

The personal athlete data: Age, Height, number of years as a professional cricketer, total number of years playing cricket, number of concussions/ helmet strikes the previous season, number of concussions in total, together with their Standard Deviation (highest, lowest and range), is shown in Table 6.3.

Table 6.3. Personal athlete data

	Age yrs	**Height cms**	**No of yrs Professional**	**No of yrs playing all Cricket**	**Concussions/Helmet Strikes last season**	**Concussions Total**
Mean	25.59	183.7	6.78	17.58	0.4	0.31
Highest	43	207	26	40	4	5
Lowest	16	147	0	1	0	0
STD	5.28	7.14	5.34	5.71	0.72	0.66
Range	27	60	26	39	4	5

Large standard deviations were found for age (5.28), height (7.14), number of years as a professional cricketer (5.34), and number of years playing cricket (5.71).

Small standard deviations were found with number of concussions/helmets strikes the previous season (0.72) and the number of concussions in total. (0.66)

The average values with standard deviation (STD) and Range for the 9 Hole Peg Test (9HPT); two attempts right hand (RH) and two attempts left hand (LH), the Single Leg Balance Test (SLBT); two attempts right leg (RL) and two attempts left leg (LL), the King Devick Test (KDT), the Concussion education questionnaire (RoCKSA-ST) are shown in Table 6.4.

Table 6.4. Scores for 9HPT, SLBT, KDT, and RoCKSA-ST.

	9 HPT RH1 (Secs)	9 HPT RH2 (Secs)	9 HPT LH1 (Secs)	9 HPT LH2 (Secs)	SLBT RL1 (Secs)	SLBT RL2 (Secs)	SLBT LL1 (Secs)	SLBT LL2 (Secs)	KDT (Secs)	RoCKSA-ST (47 points)
Average	18.77	17.90	19.34	18.47	13.33	13.46	13.71	14.34	42.18	36.45
Highest	43.90	41.62	42.70	26.07	20.00	20.00	20.00	20.00	78.9	46
Lowest	6.25	5.16	4.67	13	0.91	0.84	1.81	1.00	25.9	11
STD	2.66	2.63	2.70	2.19	6.64	6.47	6.42	6.58	7.78	5.83
Range	37.65	36.46	38.03	13.07	19.09	19.16	19.16	19.81	53.00	35

The 9 HPT data show high ranges for both right hands (37.65, 36.46 secs) and first attempt left hand (38.03 secs) the smallest range was found for left hand second attempts (13.07 secs) STD was shown to be small throughout ranging from (2.19- 2.70).

The SLBT scores show a consistent average throughout ranging (13.33– 14.34 secs) which is consistent with the highest scores seen (20 secs). The lowest scores (0.84 secs) and STD (6.42-7.78) are shown to be the key findings.

The KDT scores show a significant range of (53 secs) and a STD of (7.78) with the average score (42.18 secs).

The RoCKSA-ST Concussion Attitudes Questionnaires both have high ranges (35 RoCKSA-ST). Similarly, STD is 5.83 for RoCKSA-ST.

The professional roles of the athletes were compared to the results for the baseline tests and questionnaires in Table 6.5.

Table 6.5. Professional roles and their average scores compared to each baseline test average for the 655 participants.

Position/ Baseline Test	Number of Participants	9 HPT RH1 (Secs)	9 HPT RH2 (Secs)	9 HPT LH1 (Secs)	9 HPT LH2 (Secs)	SLBT RL1 (Secs)	SLBT RL2 (Secs)	SLBT LL1 (Secs)	SLBT LL2 (Secs)	KDT	RoCKSA-ST (47 points)
Mean.		18.77	17.90	19.34	18.47	13.33	13.46	13.71	14.34	42.18	36.45
Batsman	160	18.82	17.74	19.50	18.57	12.73	13.46	14.09	14.29	43.54	36.58
Batsman/WK	55	18.20	17.78	19.27	18.47	13.50	14.85	14.51	14.89	42.28	36.13
WKs	12	18.96	17.75	18.70	19.06	16.27	15.47	16.44	18.78	41.04	39.25
All Rounders	215	18.95	18.02	19.30	18.43	14.05	13.52	12.74	14.31	41.15	35.61
Bowlers	210	18.68	17.95	19.31	18.42	12.85	12.93	13.98	14.00	42.31	37.11

The 9HPT showed Batsman and Batsman/WKs to have the best RH1 test (18.20 secs) and RH2 test (17.74 secs). Wicketkeepers (WKs) and Bowlers had the fastest LH1 and LH2 baseline scores (18.70 and 18.42 secs). However, there was no significant differences found for any baseline testing data sets for 9HPT.

The SLBT showed that WKs have the best mean scores for all attempts (16.27,15.47, 16.44, 18.78 secs). This was significant favouring WKs for right leg (P=0.043) and left leg (P=0.002) for Batsman v. WKs and right leg (P=0.029) and left leg (P=0.001) for WKs v. Bowlers, and left leg testing between WKs v. All Rounders (P=0.000). No other significant difference was found between the other playing positions.

The KDT showed WKs to have the best mean scores (41.04 secs). Significant difference was also found between Batsman v All Rounders with (P=0.010) with no other significant difference found between other playing positions.

The RoCKSA-ST questionnaire showed that WKs had the highest mean RoCKSA-ST score (39.25/40).
For RoCKSA-ST there was significant difference favouring WKs between Batsman v. WKs (P=0.072) and WKs v. All Rounders (P=0.019). No other significant differences were found between other playing positions.

The personal data comparison for International and County standard athletes is shown in Table 6.6.

Table 6.6. Personal data comparison for International and County standard athletes

Status	Number of participants (total)	Age (Yrs)	Height (Cms)	Number of Years as a Professional (years)	Number of Years Playing all Cricket (years)	Number of Concussions/Helmet Strikes Previous Season	Number of Concussions in Total
Mean	655	25.59	183.87	6.78	17.58	0.40	0.31
International	186	29.15	183.81	10.71	21.10	0.33	0.34
County Level	469	24.19	183.89	5.23	16.18	0.42	0.30

The International Cricketers are older on average compared to county level players (29.15 v. 24.19 years) ($P=0.000$).

The International Cricketers have played professional cricket for a longer time on average (10.71 v. 5.23 years) (P0.000).

The International Cricketers have played all cricket for longer on average when compared to county level Cricketers (21.10 v. 16.18 years) ($P=0.000$).

The baseline data test comparisons for International and County standard athletes is shown in Table 6.7.

Table 6.7. Baseline data testing comparisons for International and County standard athletes

Status	Number of participants	9 HPT RH1 (Secs)	9HPT RH2(Secs)	9HPT LH1 (Secs)	9HPT LH2 (Secs)	SLBT RL1 (Secs)	SLBT RL2(Secs)	SLBT LL1 (Secs)	SLBT LL2 (Secs)	KDT	RoCKSA-ST (47 points)
Mean		18.77	17.90	19.34	18.47	13.33	13.46	13.71	14.34	42.18	36.45
International	186	18.73	17.87	19.31	18.21	13.51	13.65	14.48	14.48	42.77	35.04
County	469	18.78	17.92	19.34	18.58	13.27	13.39	13.42	14.29	41.95	37.01

The International athletes had better mean scores for every 9HPT (18.73/18.78, 17.87/17.92, 19.31/19.34, 18.21/18.58 secs) and SLBT (13.51/13.27, 13.65/13.39, 14.48/13.42,14.48/14.29 secs). However, none of these differences were significant.

The County level athletes did show faster KDT scores compared to international athletes (41.95/42.77 secs), but this difference was not significant,

The County athletes achieved higher scores on the RoCKSA-ST Concussion Attitudes Questionnaire (37.01/35.04). There was a significant difference between County athletes v. international athletes for the RoCKSA-ST (P=0.004) favouring County athletes.

6.3 Discussion

The main findings from this study are that professional cricket Wicketkeepers have the overall best mean baseline testing scores when compared to other playing positions, and they achieved 7 out of the 11 best mean scores. They performed significantly better in the SLBT compared to batsmen, bowlers and all-rounders and they had the highest mean score in KDT however, this was not significant when comparing with batsmen (P=0.390). This was not the case between Batsman v All Rounder where there was a significant difference (P=0.010) when comparing KDT scores.

International Cricketers achieved an overall better mean within baseline testing when compared to County Cricketers, but the differences were not significant. However, Educational questionnaires seem to show higher means amongst the County Cricketers. These differences were significant for the RoCKSA-ST (P=0.004).

The assumptions associated with the fact that 80-90% of concussions have a favourable outcome within 7-10-days (Lawrence and Hutchison, 2017) leads us to consider what questions should be asked of those people that do not recover within the 7–10-day window? Furthermore, how do we truly know a patient is recovered from concussion without baseline testing or subjective markers? Baseline testing is common in fields such as Sports Science and Medicine, as we have seen throughout the literature, and is regarded by physicians as an important tool when trying to rehabilitate patients back to normative scores (Cottle *et al.*, 2017).

The 9 HPT showed that Batsman and Batsman/WK had the best first right hand attempt (18.20 secs) and second right hand attempt (17.74 secs) and Wicketkeepers and Bowlers had the best first left hand attempt (18.70 secs) and second left hand attempt (18.42 secs) baseline scores. The largest difference found was between Batsman/WK right and left hands and All Rounders (only 0.88 secs) with the smallest difference between right and left hands (0.53 secs) this suggests there is little difference between left and right hand throughout the 9HPT and certainly no significant differences.

The 9-peg hole test showed STD of 2.19 – 2.70 and no significant difference was found between any groups, suggesting that the 9-peg hole normative data collected is reliable for Professional Cricketers. As previously described the 9- peg hole testing has been used throughout medical research for a baseline score and testing within diseases such as Dementia and Parkinson's patients. The normative data scores reported by Fritz *et al.,* (2016) were 31.4 ± 15.7 and 32.2 ± 12.4 s respectively, in 262 patients with impairment in motor skill performance related to sports concussion. The 9-peg hole test shows reliability, neuropsychological relevance and ease of motor skill execution needed within sports such as cricket, however, further research into other sports' normative data is needed.

Vestibular disturbances are very common after a concussion has occurred and symptoms such as dizziness and balance can be impaired and leave someone very disorientated. The balance scores showed that Wicketkeepers to have the best means between 2 attempts on each leg: right (15.91 secs) and left (17.50 secs) with a difference of 1.60 seconds being longer on the left leg. There was a significant difference found between right leg SLBT for Batsman v. Wicketkeepers (P=0.043) and Wicketkeepers v. Bowlers (P=0.029). Similarly, significant difference was also found in left leg SLBT between Batsman v. Wicketkeepers

(P=0.002), Wicketkeepers v. Bowlers (P=0.001) and Wicketkeepers v. All Rounders (P=0.000). Our findings suggest further investigation is needed into dominant foot and non-dominate foot relationships but certainly the results suggest agreement that there are different requirements between playing positions (Johnston and Ford, 2010). A Wicketkeeper's biomechanical movement patterns are conducted bilaterally compared to a Batsman and Bowler's mainly unilateral movements in these playing roles and positions, making each playing role slightly different with varying repetitive movements which may have a significant impact on successful performance. Furthermore, previous lower limb injury could impact performance especially for Bowlers who require accuracy, repeatability, and speed control when performing the skill of bowling. Poor strength and technique leads to injury in areas such as the knee joint (Rowlands, James, and Thiel 2009).

With a concussion impairing cognitive functioning and visual-motor integration, the KDT is both sensitive and valid in visual testing (Rizzo et al., 2016). The KDT baseline scores for the Cricketers show a significant range (53 secs) throughout the data sets and a STD of (7.78) with the mean score of 42.18 secs. Wicketkeeper's means were the fastest at 41.04 secs. There is limited normative data for this test but one other study by Rizzo et al., (2016) reported 51.24 (± 9.7) and a second study by Vartianinen et al., (2015) which studied 186 male professional ice hockey players with a large age range (16-40years) showed a mean time of 40.0 seconds (SD = 6.1, range = 24.0–65.7 secs). These data suggests that there is a large spread, but the important factor is that each athlete's baseline time is personal to them and will be important in informing their rehabilitation programme if they suffer a subsequent concussive injury. Furthermore, the KDT is a sensitive reliable test which is very easily conducted on the side-line or in a room near playing fields /pitches and it could be a fast and productive way of diagnosing a concussive episode when baseline data is available.

The Mental Toughness of an athlete has received significant attention within the field of psychology (Gucciardi, Hanton and Mallet 2012). Questionnaires have been used in many forums as a form of feedback within a given topic or pre- or post-situational setting. Within this study the RoCKSA-ST Concussion Attitudes Questionnaire has high ranges (35 RoCKSA-ST) STD is (5.83 RoCKSA-ST). The RoCKSA-ST questionnaire results show that Wicketkeepers have the highest RoCKSA-ST mean (39.25/40). In RoCKSA-ST there was significant differences found between Batsman v. Wicketkeepers (P=0.072) and Wicketkeepers v. All Rounders (P=0.019) with Wicketkeepers having the highest levels of knowledge. Further research into the number of head strikes or helmet strikes that occur during a cricket match or in training would help to aid a deeper understanding of why Wicketkeepers have the best overall knowledge; this may be due to their previous exposure to the signs and symptoms and running through previous concussion baseline tests such at the SCAT 4.

Findings also suggest a wide range of results and STD in the RoCKSA-ST suggesting that an improvement in the level of knowledge and understanding about concussion is needed throughout the professional ECB structure. Predicting levels of knowledge and understanding of concussion has been shown to be challenging with previous education on concussions not the best predictor according to Kurowski et al., (2014) suggesting sex is a better indication. If this is true perhaps there is a greater need to educate male professional cricketers than female professional cricketers, however, this assumption would warrant future research around predicting levels of knowledge of concussion.

6.4 Conclusion

Normative scores for baseline testing within professional International and County level Cricketers vary with only limited significant differences found within the data sets. Generalisation of data could lead to varied normative data sets with large ranges and STDs. Baseline testing throughout research has become a very useful tool and debates over individualised baselines and normative baselines are heavily debated. Schimdt et al., (2012) reported that clinicians may find normative data sets useful and reliable when no previous individual baseline test has been obtained, or when limited resources are available. With a large and varied symptomology linked to a concussive episode, reliability on one test with normative data could give misleading results. An individualised baseline testing methodology would enable an individual's rehabilitation to homeostasis to be bespoke and to take into consideration other variables that may have an effect on baselines testing scores, such as attention deficit hyperactivity disorder (ADHD) and learning difficulties (Zuckerman et al., 2013).

Within this study the RoCKSA-ST Concussion Attitudes Questionnaire has high ranges (35 RoCKSA-ST) STD is (5.83 RoCKSA-ST) this is also in continued thread from the previous pilot study showing the baseline of understanding around concussion seems to be low across professional cricket. The RoCKSA-ST questionnaire results show that Wicketkeepers have the highest RoCKSA-ST mean (39.25/40). In RoCKSA-ST there was significant differences found between Batsman v. Wicketkeepers (P=0.072) and Wicketkeepers v. All Rounders (P=0.019) with Wicketkeepers having the highest levels of knowledge.
The county athletes achieved higher scores on the RoCKSA-ST Concussion Attitudes Questionnaire (37.01/35.04). There was a significant difference between County athletes v.

international athletes for the RoCKSA-ST (P=0.004) favouring County athletes however, 469 county cricketers took the questionnaire compared to 186 international players.

The aim of this multicentre retrospective observational cohort study was primarily to determine normative baseline values in Professional Cricketers and secondary to ascertain whether there are different baseline scores for different professional roles (skill-sets). Furthermore, to understand the levels of knowledge around the area of concussion within professional cricket. It is fair to say with 655 athletes baseline screened over 18 different counties all around the UK the multicentre study was a success. It helped drive a deeper understanding around concussion and drive an intervention to help guide and deliver higher levels of care to the professional players. The use of baseline testing was cost effective and valid across the entire ECB.

Chapter 7.0 Developing the Knowledge and Understanding of Concussion within Professional Cricket

7.0 Introduction

Education leads to a better understanding around a topic and informed and better choices when decisions need to be made. Doctors, surgeons, and physiotherapist alike have to study for many years to gain in-depth knowledge of healthcare which allows them to give the very best care to patients when needed. Developing such expert knowledge takes time and has been taught through traditional teaching methods for many years. However, it has been shown that constructivist learning environments do help develop prerequisites for expert knowledge (Tynjala, 1999). Therefore, open minded and alternative ways of learning may be beneficial for diversifying knowledge in and in around topical areas such as concussion.

Many questions arise about methods of teaching and learning. Thorne (2003) questioned when the last time was that learners really felt inspired to learn! Integrated learning and guided discovery have been shown to be a beneficial way of learning. Ardianto and Rubini (2016) discovered that student literacy achievement improved through an integrated approach to science within a problem-solving group. Learning through participation with multisensory environments that combine the physical and the visual have been shown to be beneficial to the learner. Computer games demonstrate interactive learning and non-formal learning environments for children are backed up by the theoretical notion that physical play is an essential characteristic in the learning processes (Roussou, 2004).

The understanding of a medical condition or injury can be the difference between reinjury through returning to work or sports to soon, or to more tragically, missing a cancer diagnosis. Technology has increased our ability to connect people all over the world at any given time. Online video-based patient education compared to written information has been shown to significantly improve Melanoma awareness when 78 subjects took a 10-item questionnaire 1-month post melanoma review (Idriss et al., 2009).

The aim of this research was to ascertain whether the baseline testing study, carried out over a 3-year period, had changed the levels of knowledge and attitudes toward concussion within the English professional cricket clubs.

7.1 Methodology and Materials

The RoCKSA-ST concussion knowledge and attitudes questionnaire was described and explained in Section 3.1.

7.2 Results

The RoCKSA-ST scores with STD achieved by the athletes (including mean athlete age) in years 2016, 2017 and 2018 are shown in Table 7.1 and Table 7.2. The percentage of the year group who correctly answered the question on the Signs and Symptoms (S&S) of concussion is displayed in Table 7.1.

Table 7.1. Mean and STD scores for the RoCKSA-ST for years 2016, 2017, 2018.

Year	Mean Athlete Age	RoCKSA-ST (Max-47 points) (STD)	All S&S identified (percentage of population)
1-2016	26.05	35.65	2%
		6.06	
2-2017	25.38	36.38	5%
		5.68	
3-2018	25.70	36.66	6%
		5.93	

Table 7.2. Comparison by years for RoCKSA-ST Concussion Attitudes Questionnaire

RoCKSA-ST Q Sig Diff	P value
Year 1 -2	0.394
Year 1-3	0.249
Year 2-3	0.547

7.3 Discussion

Over the past decade there has been an increase in awareness and of concussion within sport (Tator, 2012). This can only be a positive improvement as the more we know and understand as players and coaches then the more likely that physicians will be prepared to diagnose and manage concussive episodes that occur within professional sports (Tator, 2012). This would then lead to more accurate removal from match play and training sessions for players, allowing them to have the right care over the injured period. This then could impact the return to play process for players and enable them to get back to playing and training quicker and more efficiently.

The enforcement of the rules of any sport and evaluation of any injury plays a critical part in preventing concussion (Tator, 2008). The results within Table 1 show that in year 1 (2016) the mean score was 35.65 with an STD of 6.06. This would suggest that levels of knowledge are low with a wide range around the mean. Furthermore, the mean age of the athletes was 26.05 years with a range of 20 years; the oldest being 37 yrs and youngest 17yrs suggesting that past education around the topic of concussion may have been low or non-existent during the 2016 season. With lower levels of education and understanding around injury self-diagnosis limited, this could lead to pour self-reporting of the signs and symptoms of concussion by the professional players. This then could increase the risk of second impact syndrome and prolong the return to play process. In extreme circumstances, I have seen first-hand athletes who have retired due to continuous head injuries losing careers and incomes, leaving them without work and suffering subsequent mental health issues. This demonstrates the true seriousness of the issues around education for all players and staff within the professional sports world.

There was no significant difference when comparing results from years 1-2 (P=0.394). However, in year 2 (2017) there was an increase in the number of athletes answering the Signs and Symptoms (S&S) of concussion correctly compared to year 1 (5% compared to 2%), suggesting an increase of understanding of S&S. This improved understanding could help with the levels of anxiety that an athlete may have when injured. Many athletes rely heavily on their support networks from family (89%), friends (78%), teammates (65%) and coaches (47%) during an injury and it is important to educate as many people as possible around concussive symptomology (Covassin et al., 2014). Covassin et al., (2014) showed that anxiety levels were similar between orthopaedic injuries and concussive episodes when greater support was shown by coaches towards orthopaedic injuries. Bridging the gap in knowledge and understanding by education may lead to a better understanding and sympathy towards concussed athletes. Year 2 (2017) showed an increase in the mean score to 36.38 from the athletes suggesting knowledge is increasing. If levels of education increase throughout professional cricket and coaches also understand the sign and symptoms more this could lead to more empathy towards players. The understanding of how serious the injury can be may allow players to also report more honestly if they do have any signs and symptoms of concussion without the anxiety of not being selected for the following matches if they are unable to train or play. This was also suggested in research with 50% of athletes not reporting their symptoms within US high school athletes (Beran and Scafide, 2022)

Between Years 2-3 there was a slight increase in the S&S following from years 1 -2. Year 3 showed that 6% of athletes answered all S&S correctly and the average score for the RoCKSA-ST Concussion and Attitudes questionnaire increased again from year 2 to 36.66.

However, this result was not significant (P= 0.547). When comparing year 1-3 there was still no significant difference despite a slightly improved significant difference (P=0.249).

The findings show a tendency toward increased knowledge and attitudes towards concussion by athletes in professional cricket. This may influence the recording of a concussion, thus allowing for improved diagnosis and intervention, in turn facilitating rehabilitation. The evidence suggests that although the long-term effects of traumatic brain injury (TBI) are not completely known, it is suggested that an individualised approach to concussion may improve recovery (Pettemeridou et al., 2020).

Other collision sports such as Rugby Union are popular all across the world in Europe, Africa, Australia and New Zealand with concussion rates high due to no protective equipment and the tackle causing the highest injury rates due to the velocities occurring (Selenke, 2020). Suggestion of increased knowledge due to high rates of concussion and the need to side-line players if a concussion episode has occurred has meant that English Rugby Football Union (RFU) has tried to educated players, staff and coaches around the area of concussion through varying methods. Most recently through an online educational assessment and exam of which all players and staff must complete and pass before contact training is to start. Through this method they are trying to increase awareness and diagnosis to allow better player welfare procedures. Future research into an educational module within professional cricket may not be warranted due to the rates of concussive episodes that occur. However, a recent study of 866 adolescent Rugby Union Players has shown that (70%) under reported concussion due to them “not thinking the injury was serious enough” (38%) “wanting to win the game” and (48%) “not wanting to miss future games or training” (Beakey et al., 2020). These are all worrying findings and further investigation into

Cricketers is needed. However, there is still a need for basic knowledge and understanding to increase within Professional Cricketers to allow future research to continue and players to have a true understanding of the symptomology they are incurring after a concussion has occurred to allow correct reporting and diagnosis.

7.4 Conclusion

Any health education in sport should always include the prevention of sports injuries. The key for teaching and education on any topic is to first understand the magnitude of the problem (Kok and Bouter 1990). Therefore, gaining an understanding of the levels of concussion and the knowledge and attitudes of participants in that sport to concussion, is critical to improving diagnosis and player welfare. Overall education levels around the topical area of concussion increased over the 3- year period of this study presumably due to the baseline testing and the educational video-based learning. However, further research should also consider that any athlete and member of medical staff might investigate the topic on their own, which in turn could increase their levels of knowledge and change their attitudes.

Chapter 8. Baseline Testing Professional Rugby Union Players

8.0 Introduction

Traumatic brain injury unfortunately occurs throughout all aspects of life including War (Myers, 1915) and Professional sports such as Rugby Union (Kirkwood et al., (2014). In the National Health Service (NHS) sports related concussion is a common occurrence (Mourouzis et al., 2005). The impact site of the concussion changes from patient to patient and biomechanical influences can provide insight into a concussive episode allowing an understanding of the interrelationships between the forces.

Within Rugby Union baseline testing and rehabilitation are common practices within an athlete's training program (Cochrane and Monaghan 2018). The Rugby Union return to play guidelines which describes a 6-phase methodological approach were created by World Rugby for clinical physicians and includes baselines for a safe return to play. Rafferty *et al*., (2019) in a study across elite level Rugby Union during seasons (2012/2013-2015/2016) found that players are at a higher risk of a concussion in any season after 25 matches (95%CI 19 to 32) with 50% of concussions occurring in the tackle.

The purpose of this retrospective observational cohort study was to gain an understanding of normative baselines in Rugby Union Players. This opportunity presented itself through an introduction from my supervisor to some of the leading medical departments within Rugby Union - due to the good work that was been done within the ECB. It was debated if the baseline testing procedure would also work within another sporting environment and within a collision sport such as Rugby Union. With my personal background having played professional Rugby Union and also working within the sport it was a great opportunity to compare if baseline testing could also have a positive influence in another sport. With the interesting findings within professional cricket around the understanding of signs and symptoms of concussion the opportunity that presented itself to access rugby union professional players and conduct baseline testing was one that could not be turned down.

8.1 Methodology and Materials

Medical staff in Rugby Union Clubs were invited to participate in the study by telephone and email. The rational of baseline testing was explained together with the protocols and information about the study procedures (Section 5.1). The benefits to each Rugby Club were discussed, together with the Rugby Football Union (RFU) duty of care toward their players. The study was conducted over a 2-year period within the preseason time frame (June-September).

Athletes from Clubs in the Premiership, Championship and National One took part in the study. Players were recruited and assessed non-invasively by the same neurophysiological and neuropsychological tests described in Sections 5.1involving Professional Cricketers. The tests involved the four main areas which concussion is known to impair: balance; coordination; reduced speed of ocular processing and movement; cognition and recall thus creating a baseline data set for each player.

On baseline testing day, the athletes were informed what their participation would involve and each baseline tests explained. A consent form was handed out and signed in accord with the International Conference on Harmonisation (ICH) and Good Clinical Practice (GCP). This was accompanied by an in-depth PDF document for each athlete explaining each step of the baselines test procedures.

All assessments and data collection were carried out under strict confidentiality with all athletes providing basic demographic data including age, nationality and information on their sporting history consisted of number of years playing professional Rugby Union, total years playing Rugby Union, total number of concussions, and position(s) played.
All assessments were conducted by a team of volunteers ranging in experience from General Practitioners, Hospital Consultants, RFU employees, University PhD students, Research Fellows or Research Assistants. Standardisation of tests and teaching took place throughout the research and before each testing day, so the assessors minimized inter-examiner error. All baseline testing took place over a one to two-day period at the appropriate Rugby Union Club.

8.2 Results

A total of 144 male athletes were screened and categorised by highest level played; International, International A, Premiership, Championship, National 1 and National 2, and by their playing position; Prop, Hooker, 2nd Row, Back Row, Scrum Half, Fly Half, Centre, Winger and Fullback. See Table 8.1.

Table 8.1. Professional Rugby Union players mean anthropometric data with highest, lowest, standard deviation (STD) and ranges.

	Height (cm) Mean	**Age (years) Mean**	**Yrs as a Professional Mean**	**Yrs Playing Rugby Mean**	**Total Number of Concussions Mean**
	186.4	24.1	4.7	14.8	2.2
Highest	210	36	18	31	30
Lowest	171	18	0	5	0
STD	7.47	4.11	4.34	4.63	3.25
Range	39	18	18	26	30

The results obtained for the 9 Hole Peg Test (9HPT) twice by right hand and twice by left hand, the Single Leg Balance Test (SLBT) twice for right leg and twice for left leg, the King Devick Test, and the RoCKSA-ST questionnaire are shown in Table 8.2 with mean values, highest, lowest, STD and ranges are shown in Table 8.2.

Table 8.2. Professional Rugby Union players Mean, highest, lowest, STD and ranges for 9HPT, SLBT, KDT, and ROCKSA-ST.

	9HPT RH1 (Secs) Mean	9 HPT RH 2 (Secs) Mean	9HPT LH 1 (Secs) Mean	9HPT LH 2 (Secs) Mean	SLBT RL1 (Secs) Mean	SLBT RL2 (Secs) mean	SLBT LL1 (Secs) Mean	SLBT LL2 (Secs) Mean	KDT Score Mean	RoCKSA-ST (47 pts) Mean
	18.93	17.85	19.41	18.67	16.03	16.76	16.89	17.30	42.56	39.02
Highest	28.09	24.66	25.00	25.53	20.00	20.00	20.00	20.00	67.8	45
Lowest	13.77	13.18	14.12	14.37	2.56	3.47	2.91	3.00	16.5	26
STD	2.39	2.20	2.19	1.93	5.74	5.28	5.07	4.68	7.78	3.45
Range	14.32	11.48	10.88	11.16	17.44	16.53	17.09	17.00	51.30	19

The anthropometric data from Table 8.1 is presented in Table 8.3 with reference to playing position.

The Second-row players are the tallest with a mean of 199.8 cm.
The Centres are the oldest with a mean of 25.6 yrs, have the highest number of years as professionals (6.4 yrs), the highest number of years playing Rugby (17.7 yrs), and the highest number of concussions (4.1).

Table 8.3. Professional Rugby Union players baseline means for height, age, number of years as a professional, number of years playing Rugby Union and number of concussions by playing position.

Table 8.3. Professional Rugby Union players baseline means for height, age, number of years as a professional, number of years playing Rugby Union and number of concussions by playing position.

Position	Number	Height (cm) Mean	Age (yrs) Mean	Yrs as a Professional Mean	Yrs Playing Rugby Union Mean	Total Number of Concussions Mean
		186.4	24.1	4.7	14.8	2.2
Prop	23	185.5	24.3	5.1	13.3	1.6
Hooker	16	181.7	24.3	5.7	15.1	1.4
Second Row	15	199.8	24.7	4.0	14.6	2.7
Back Row	30	190.1	24.3	4.9	14.5	2.2
Scrum Half	9	175.8	24.6	5.1	17.2	2.3
Fly Half	12	182.4	23.8	5.2	15.3	1.9
Centre	13	187.6	25.6	6.4	17.7	4.1
Winger	16	182.9	23.2	2.8	14.4	2.1
Full Back	10	183.5	22.0	3.1	13.2	1.5

Position	9HPT RH1 (Secs) Mean	9HPT RH2 (Secs) Mean	9HPT LH1 (Secs) Mean	9HPT LH2 (Secs) Mean	SLBT RL1 (Secs) Mean	SLBT RL2 (Secs) Mean	SLBT LL1 (Secs) Mean	SLBT LL2 (Secs) Mean	KDT Score Mean	RoCKSA-ST (47 pts) Mean
	18.93	17.85	19.41	18.67	16.03	16.76	16.89	17.30	42.56	39.02
Prop	19.4	18.2	19.5	18.9	15.1	16.2	17.0	16.5	44.1	38.9
Hooker	19.0	17.7	19.8	18.8	16.6	16.3	15.1	16.5	44.0	40.7
Second Row	20.4	18.3	18.8	19.1	14.1	14.4	16.5	18.0	41.9	39.8
Back Row	18.5	17.7	19.8	18.6	14.8	15.9	16.8	16.6	42.7	38.3
Scrum Half	18.9	18.3	18.5	18.5	18.1	19.5	17.6	20.0	41.3	39.0
Fly Half	19.0	18.0	19.0	18.2	18.2	18.1	16.0	15.2	40.7	40.1
Centre	18.5	18.0	19.3	18.5	15.6	16.5	18.8	18.8	41.8	37.8
Winger	18.1	17.4	19.2	18.3	17.4	18.4	16.7	17.3	43.6	38.1
Full Back	18.5	16.9	20.0	19.2	17.8	18.0	18.9	20.0	39.8	39.3

Table 8.4. Professional Rugby Union players baseline mean scores by playing position.

An unequal variance t-test was conducted on data sets to interpret any P-value between baseline testing scores and playing positions.

Significant difference was found in 9- hole peg test (9HPT) right hand scores between Front Row (Props and Hookers) v Back Three (Wingers and Fullbacks) (P= 0.029).

Significant difference was also found between Back Five (2nd Row and Back row) v Back Three (Wingers and Fullbacks) (P= 0.042).

There was a tendency for Forwards (Prop, Hooker, Second Row, Back row) to score slightly less for all SLBTs but this was not significant ($p>0.05$). However significant difference was found between SLBT Right Leg scores between Front Row v Back Three (wingers and fullbacks) (P= 0.031), Back five (second row and back row) v Stand-off (fly half and scrum half) (P=0.006), and Back Five (second row and back row) v Back three (wingers and fullback) (P= 0.001). No significant difference was found for any other single leg balance scores and playing position.

There was a tendency for Backs (Scrum Half, Fly Half, Centres, Wingers, Full Backs) to be quicker on the King Devick Test (KDT) but this was not significant ($p>0.05$). Full backs had the quickest KDT with a mean score of 39.8 secs.

The highest RoCKSA-ST questionnaire result was 40.7/47. There was no significant difference in RoCKSA-ST and playing positions.

The data from Table 8.1 is presented in Table 8.5 by highest level played.

Table 8.5. Professional Rugby Union players baseline means for height, age, number of years as a professional, number of years playing Rugby and number of concussions by highest level played.

	Number of players	Height (cms) Mean	Age (yrs) Mean	Yrs as a Professional Mean	Yrs Playing Rugby Mean	Total Number of Concussions Mean
		186.4	24.1	4.7	14.8	2.2
International	23	186.6	28.4	9.0	18.8	2.0
Premiership	51	186.6	24.6	6.2	15.5	3.2
Champ & Below	70	186.2	22.4	2.3	13.0	1.4

The International Rugby players are older (mean 28.4 yrs) compared to the Premiership (24.6yrs) and Championship & below (22.4 yrs).

The International Rugby players have played professional Rugby for a longer time (mean 9 yrs 0 compared to Premiership 96.2 yrs) and Championship & below (2.3 yrs).

The International Rugby players have played Rugby for longer (mean 18.8 yrs) when compared to Premiership (15.5 yrs) and Championship & below (13 yrs).

The Premiership Rugby players have incurred the highest number of concussions (mean 3.2) compared to International (mean 2) and Championship & below (mean 1.4).

The data from Table 8.2 is presented in Table 8.6 when comparing baseline scores by playing level.

Playing Level	9HPT RH1 (Secs) Mean	9HPT RH2 (Secs) Mean	9HPT LH1 (Secs) Mean	9HOT LH2 (Secs) Mean	SLBT RL1 (Secs) Mean	SLBT RL2 (Secs) Mean	SLBT LL1 (Secs) Mean	SLBT LL2 (Secs) Mean	KDT Score Mean	RoCKSA-ST (47 pts) Mean
	18.93	17.85	19.41	18.67	16.03	16.76	16.89	17.30	42.56	39.02
International	18.6	17.2	19.4	18.3	17.0	18.8	18.4	19.1	43.0	38.2
Premiership	18.9	18.3	19.4	18.9	16.3	17.0	17.4	18.7	42.6	39.4
Champ & Below	19.1	17.8	19.4	18.6	15.5	16.1	16.0	16.1	42.4	39.0

Table 8.6. Professional Rugby Union players baseline mean scores by playing level.

An unequal variance t-test was conducted comparing baseline testing scores and highest level played International, Premiership and Championship & below.

The International Rugby players generally showed better mean scores in 9-peg hole testing, but the difference was not significant ($p>0.05$).

The Championship & below Rugby players have marginally faster means on the King Devick Test but the difference was not significant ($p>0.05$).

The Premiership Rugby players showed the highest level of knowledge in the RoCKSA-ST Concussion Attitudes questionnaire (39.4 /47) but this difference was not significant ($p>0.05$).

8.3 Discussion

Rugby Union is very popular throughout the world especially in New Zealand (NZ) where it has become embedded within NZ culture. A high number of participants results in a high number of injuries and 50% of maxillofacial injuries in NZ occur whilst playing Rugby Union (Lee, 2008). Baseline screening will lead to a deeper understanding of normative and individual baseline scores, increase levels of knowledge and understanding, and in turn improve mental toughness and anxiety; so important in contact sports such as Rugby Union.

Large ranges were found in our general demographic information. The centres had the oldest mean age and not unusually the highest number of years as professional players (6.4 yrs), the highest number of years playing rugby (17.7 yrs), and the highest number of concussions (4.1). This pattern was also shown by Frass et al., (2014) suggesting that centres and backs in general were more susceptible to concussion. A significant finding, however, was the range of the number of total concussions (0-30), alongside large ranges in the number of years professionals (0-18 yrs), suggesting the longer you play Rugby Union the more concussions you will incur as playing time increases. The increased risk of a concussive episode was associated with increasing match hours and was demonstrated in a meta-analysis of 37 studies by Gardener (2014) which reported an overall incidence of match-play concussion in men's Rugby (15 a side) of 4.73 per 1,000 player match hours. Furthermore, the findings in this study that a professional Rugby Union player has had as many as 30 concussions is frankly horrifying. Further research into how many concussive episodes are actually reported to team physicians needs to be conducted. There is evidence that players under report for fear of removal from the game (Fraas et al., 2014). Large STDs were seen across all general demographic information in this study. Any further study would need to have a larger number of study participants to increase the power of the study. Drawing significant conclusions from only a study population of only 144 will be impossible.

The 9-peg hole tests dexterity, coordination and motor skills all of which are needed within Rugby Union and have potential to be affected within a concussion. The 9-peg hole results show similar mean baseline scores for right hand 1&2 (RH1 and RH2) and left hand 1&2 (LH1 and LH2) with both second attempts marginally faster which may be due to 'learning' the test. The STD was small suggesting that all players irrespective of position and level have a similar mean score. However, significant differences were found in the 9-peg hole right scores between Front Row players (Props and Hookers) v Back three players (Wingers and Fullbacks) favouring Back three players (P= 0.029) and between Back five (2nd Row and Back row) v Back three also favouring Back three players (P= 0.042). This fits with the expected increased dexterity of a Back three player compared to a Forward. No significant difference was found for any 9-peg hole scores and other playing positions.

Due to vestibular disturbance post concussive impact, balance has shown to be impaired in many studies, not only in the acute phase but also in the longer term and more longitudinal research is needed (Danes- Anyadike and Brown 2016). The SLBT could therefore show potential differences to normative baseline scores post-concussion. SLBT scores show similar high scores at 20 seconds (the timed cut off point). with good times seen throughout all single leg attempts with a high range of scores across all right leg 1&2 and left leg 1&2 attempts (16.53–17.44 secs) with high STDs also seen (4.68-5.74). Significant difference was found between SLBT right leg scores between Front Row v Back three favouring Back three, (P= 0.031) Back five v Stand-off (fly half and scrum half) favouring Stand-off (P=0.006) and Back five v Back three favouring Back three (P= 0.001). All these significances might be expected and the balance and agility of a Back three players and Stand- offs should be superior to forward players. Why did significance only show on the right leg? Perhaps this was the dominant leg in the majority of study individuals. No significant difference was found for any other single leg balance scores and playing position. Limitations to the study design would suggest that people with pre-existing injuries need to be considered in future research which should include a full injury history.

Impaired cognitive functioning can leave an athlete struggling to process information which is critical to performing in sports. The risk of second impact syndrome (SIS) makes it dangerous for an athlete to continue playing after a concussion. Concussive effects which remain require long periods of rehabilitation including a multidisciplinary, symptom-targeted treatment approach that can include cervical spine rehabilitation, sub-symptom threshold exercise training, vestibular and visual therapy, psychological cognitive behavioural therapy, academic/work adjustments, and lifestyle changes involving sleep hygiene, and nutrition/hydration (Turner and Labella 2019). This demonstrates how important it is to recognise concussion and remove the athlete from play. The KDT can be performed pitch side and in this study the mean time to take the KDT was only 42.56 secs, giving instant feedback to a physician and negating any risk of SIS if a player was not removed. The longest time recorded for the KDT was 67.8 secs and the fastest 16.5 secs, demonstrating a range of 51.30 seconds and a STD of 7.78. Fullbacks had the fastest mean time for all the playing positions (39.8 secs). Interestingly visual scanning and assessment of player positions is a critical skill of a Full back, but no significant difference was found between KDT scores and playing positions. Reliability of KDT when combined with another test eg. Pitch Side Concussion Assessment Version 2 (PSCA2) has shown up to 89% reliably in diagnosing a concussive episode (Molloy et al., 2017). Therefore, KDT as a baseline testing tool coupled with other baseline test has the potential to bed an impactful screening tool.

Head Injury Assessment (HIA) screening uses a SCAT (Sports Concussion Assessment Tool) in many sports including Rugby Union (Fuller et al., 2020). The SCAT assessment is used to help diagnose a concussion through varying questions on symptomology, cognitive functioning and motor function. The assessment relies in part on the patient explaining their symptoms. However, the athlete may not divulge their symptoms due to fear of been removed from play. Furthermore, the athlete may not feel the signs and symptoms are severe or even related to concussion due to their lack of knowledge and understanding around concussion.

The RoSKSA-ST Knowledge and Attitudes concussion questionnaire showed an average score for players in this study of 39.02/47 showing fair levels of knowledge. The highest score was 45/47 and the lowest 26/47 with a range of 19 and a STD of 3.45 demonstrating similar levels of knowledge in all playing positions and levels. The Hookers showed the highest levels of knowledge with an average scoring 40.7/ 47. Some 24% (34 participants) of the participants correctly answered all the signs and symptoms correctly within the appropriate questionnaire section. No significant difference was found for any playing position with the RoCKSA-ST questionnaire score. Education as a tool is used to improve knowledge and understanding in every sphere of life. It is hoped that baseline testing and education interventions will increase the correct diagnoses and decrease the missed diagnoses over time.

Comparing highest levels played against baseline scores may reveal recognisable trends. The athletes were divided into 3 groups by level played: 23 International players, 51 Premiership players and 70 Championship & below players. International players and Premiership players had a greater mean height (186.6 cms). International players had the oldest mean age (28.4 yrs) and the longest mean time in Professional Rugby and the longest mean time playing all Rugby. Premiership players had the highest mean number of concussions (3.2). The findings suggest that International players have superior baseline 9HPT scores for both hands and both attempts compared to both Premiership and Championship players except for left hand 1 (LH1) where they all scored 19.4 secs. Furthermore, SLBT scores for all attempts on both legs are superior for International players 17 – 19.1 secs. Differences were significant for left leg balance scores for International v Championship & below, favouring International (P=0.000) and Premiership v Championship, favouring Premiership (P=0.004). Furthermore, significant difference was also found for right leg scores for International v Championship & below, favouring International (P=0.016). The KDT scores were quickest for Championship players and below with a mean of 42.4 secs. The highest level of knowledge was found within the Premiership group with a mean score of 39.4 /47. This was followed by the Championship & below players with 39/47 with the International players with 38.2/47. No significant difference found between any groups except in SLBT balance scores (see above) and it is fair to suggest that levels of understanding about concussion within Rugby Union is even at all three levels described in this study.

8.4 Conclusion

The large STDs and ranges in the baseline data demonstrate the importance of individualised baseline scores for each player. The normative data sets for playing position and level played will help guide general normative baselines within the baseline testing procedures. Collecting individual baselines scores may be time consuming but the advantage of an individualised rehabilitation approach after any concussive episode is clear. Pushing players too hard in rehabilitation without any objective markers in return to play protocols will result in time lost when there is recurring symptomatology. Signs and symptoms (S&S) knowledge at 24% needs addressing through widespread baseline testing and future research into levels of knowledge and attitudes. This would improve concussion diagnoses, reduce incorrect diagnoses, decrease Second Impact Syndrome (SIS) and reduce mental health issues later in life.

When comparing the knowledge of the groups of Rugby Union players, the highest score on the RoCKSA-ST was 45/47 with an average of 39.4/47. When comparing to Professional cricketers 39.25/47, the best mean score seen from the wicketkeepers not to dissimilar to the mean score from the Rugby Union players. However, the highest Professional Cricket score was 46/47, which was higher than the highest Professional Rugby player's score of 45/47. When comparing results, the Professional Cricketers was over a 3 year period and the Professional Rugby Union players was over a 2 year period, therefore this has to be considered when comparing results. Normative baselines also do not take into consideration the varying individuals symptoms of concussion and therefore the score should be considered on an individual basis.

Chapter 9. Levels of Knowledge and Understanding of Concussion; a comparison between Junior Doctors and Professional Rugby players

9.0 Introduction

Concussion has been linked to contact collisions in American Football, Rugby Union and Ice Hockey since the early 1980s. However, the consensus definition of concussion in sport was only established in 2008 (McCory et al., (2009) due to the lack of knowledge and understanding of its signs, symptoms and management (Harrison, 2014; Turner, 2019).

Concussion affects a large proportion of athletes professionally and socially, as well as the general public who sustain injuries during their everyday tasks and activities. However, physicians carry the burden of diagnosis, in reality often without any technological help, and relying solely on the patient's own personal awareness of their signs and symptoms. Future development of concussion care will depend on whether education increases around concussion. Will the NHS and physicians be able to cope with the influx of self-diagnosing patients seeking assistance and will the inevitable reoccurrence of symptoms from patients not following a long-term rehabilitation programme affect the demand on public service (Ahmed and Weiler 2006).

Concussion sustained whilst participating in sport is a common occurrence within the NHS (Phillips et al., 2016). High-level (professional) sports usually employ team physicians to look after athletes medically and physically while the rest of sport and the majority of the public head to the Emergency Department. However, it has been shown by Philips et al., (2016) that there is a lack of knowledge and understanding around concussion within health professionals working in the UK. Their research by questionnaire tested the health professional's understanding of signs and symptoms of concussion. They asked whether there were differences in the management of adult and paediatric concussion together with questions regarding Return to Play (RTP) guidelines and the use of potentially protective equipment. NHS Consultants obtained the highest score (6.2) within the signs and symptoms section with NHS Specialist Registrars the lowest (2.0), suggesting that even the professionals diagnosing concussion need more knowledge and education.

Investigation into the levels of knowledge and understanding of physicians may lead to a deeper understanding of the complex symptomology that has to be obtained from patients prior to diagnosis. Physicians must be at the forefront of education in this area to enable consistent, reliable and fast diagnoses. It is highly unlikely that every professional sports player will gain a high level of understanding in and around concussion and injuries in sport. However, physicians and the NHS is something we all use and trust when injury or illness occurs, therefore we trust in their judgement and diagnosis, and one would expect high levels of knowledge around concussion baseline testing and signs and symptoms.

Baseline testing is used within professional sports, however, it is not able to be completed over the entire general public as it is simply not possible, but if baseline tests are cost effective, time effective, and easily conducted it could be considered for use across sports at grass route level therefore capturing a wider use case.

9.1 Methods and Materials

Prior to a lecture at the Queen Elizabeth Hospital, Birmingham in September 2018, 48 maxillofacial surgery junior doctors undertook the RoCKSA-ST Concussion Attitudes Questionnaire. This was to assess their knowledge and attitudes towards concussion. After a full explanation of the questionnaire, they were given the option to withdraw before their verbal consent was obtained. The questionnaire was conducted in exam conditions with participants sitting 2m apart and in silence with no conferring to questions.

The questionnaire contains 25-items relating to concussion knowledge (knowledge index) and 15-items relating to attitudes towards concussion (attitudes index). The questionnaire takes approximately 10 minutes and the highest score possible is 47. The knowledge index has a reliability of 0.67 and the attitudes index has a reliability of 0.79 (Rosenbaum and Arnett 2010). This was the same questionnaire conducted by Professional Cricketers, Rugby Union players and Rugby League players.

In order to compare the results 58 questionnaires were also completed by Professional Cricketers (Pilot study) 61 Professional Rugby Union players during baseline testing days and 64 Professional Rugby League players during baseline testing days.

The purpose of this retrospective observational cohort study was to compare the attitudes and knowledge of concussion of Junior doctors with those of professional Cricket players, Professional Rugby Union players and Professional Rugby League players.

9.2 Results

The mean scores for the junior doctors, Professional Cricketers, professional rugby union players and professional rugby league players are shown in Table 9.1.

All groups	Number in sample	Highest Possible Score	Mean questionnaire Score	Highest Score	Lowest Score	STD.	Section 1 average (18)	Section 2 average (3)	Section 3 average (8)	Section 4 average (10)	Correct Signs & symptoms recognised (8)	Wrong Signs & symptoms attributed to concussion	All signs & symptoms recognised correctly with no wrong symptoms selected
Doctors	48	47	38.31	43	24	5.17	13.8	2.4	7.3	7.7	5.9	2.2	6%
Cricketers	58	47	35.65	44	19	6.06	12.8	2.4	6.7	6.9	5.8	2.3	2%
Rugby Union	61	47	38.30	44	26	4.03	13.7	2.4	6.5	8.3	7.4	2.0	28%
Rugby League	64	47	36.86	43	29	3.23	13.7	2.4	6.3	7.6	6.9	1.8	17%

Table 9.1. Mean scores in each section of the ROCKSA-ST for each group.

The sample sizes, highest possible score, mean questionnaire score, highest score, lowest score and standard deviation between groups are shown in Table 9.2.

All groups	Number in sample	Highest Possible Score	Mean questionnaire Score	Highest Score achieved	Lowest Score achieved	STD.
Doctors	48	47	38.31	43	24	5.17
Cricketers	58	47	35.65	44	19	6.06
Rugby Union	61	47	38.30	44	26	4.03
Rugby League	64	47	36.86	43	29	3.23

Table 9.2. Comparison of scores between groups

The mean scores in each section by groups are shown in Table 9.3

All groups	Section 1 mean (18)	Section 2 mean (3)	Section 3 mean (8)	Section 4 mean (10)
Doctors	13.8	2.4	7.3	7.7
Cricketers	12.8	2.4	6.7	6.9
Rugby Union	13.7	2.4	6.5	8.3
Rugby League	13.7	2.4	6.3	7.6

Table 9.3. Mean Scores by section comparison between groups.

The comparison between Groups of the mean percentage scores for the correct signs and symptoms recognised, the mean percentage scores for the wrong signs and symptoms attributed to concussion, and the mean percentage scores when all the correct signs and symptoms were recognised with no incorrect symptoms selected, are shown in Table 9.4.

All groups	Correct Signs & symptoms recognised (8)	Wrong Signs & symptoms attributed to concussion	All signs & symptoms recognised correctly with no wrong symptoms selected
Doctors	5.9	2.2	6%
Cricketers	5.8	2.3	2%
Rugby Union	7.4	2.0	28%
Rugby League	6.9	1.8	17%

Table 9.4. Comparison between Groups for correct signs and symptom recognition

An unequal variance t-test was conducted on data sets to interpret any significant differences between groups. Significant difference was only found between Professional Rugby Union players and Junior Doctors P=0.03. There was no significant difference found between Professional Cricketers and Junior Doctors (P=0.2) and Professional Rugby League players and Junior Doctors (P=0.81)

9.3 Discussion

Junior Doctors performed no better than Professional Cricketers (P=0.2) and professional Rugby League players (P=0.81) and significantly worse that Professional Rugby Union players (P=0.03) on the ROCKSA-ST Concussion Attitudes Questionnaire. There were very little differences in the results in Table 9.1, Table 9.2 and Table 9.3 and only when the correct recognition of signs and symptoms without any incorrect answers was considered was any significance reached. It is possible that the increased knowledge shown by the Rugby Union group could be due to the number of personal concussions that participants had sustained. This was reported in other sports by Stevens et al., (2008).

More needs to be done to improve Junior Doctors knowledge of the signs and symptoms of concussion. A recent study revealed that of 500 patients attending Queen Elizabeth Hospital, Birmingham for maxillofacial injuries, only 93 (19%) were referred for a neurosurgical opinion, and 186 (33%) having had a concussion, should have had more post-trauma concussion follow up (Hammond et al., 2018). Therefore, are patients not getting referred due to a lack of knowledge and understanding of concussion or are physicians and patients misdiagnosing the signs and symptoms of concussion from the outset?

The individualised signs and symptoms of concussion are many as discussed within the literature review and every rehabilitation should potentially be individualised. Recent studies have shown that 80-90% of symptoms will naturally resolve within 10 days without any intervention. (Cross et al., 2016 and McCrory et al.,2016), leaving 10-20% of patients with a potential longer recovery process. with persistent symptomologies that are consistent for many months such as headaches, dizziness, loss of memory and disturbed concentration

(Alves et al., 1993 and Willer & Leddy 2006). This could have severe consequences on the patient's mental health and finances throughout this period of recovery which in turn could lead to other health issues such as anxiety (Brogilo et al., 2015). Thus, improving Junior Doctor's levels of knowledge and understanding are ever more important as accidents, sports and non- sports-related injury and TBI are all a common occurrence within the UK's National Health Service (NHS) and are seen in every Emergency Department (Provvidenza and Johnston, 2009).

This study shows that all groups lacked knowledge and understanding of concussion even though Professional Rugby Union Players were statistically better. Education is a key part in the process of improving the levels of knowledge and understanding of concussion. Sullivan et al., (2018) reported on data collected on 428 athlete concussions during 2016-2017 and showed the positive effect of education on athlete's levels of knowledge.

An athlete's life span in sport is only one part of their life and this needs to be considered in any decision-making process. If signs and symptoms are not recognised effectively, the correct protocols may not be followed to limit the risk to an athlete long-term from playing sooner than they should, and the possibility of a second impact occurring when the athlete has not fully recovered causing Sudden Impact Syndrome SIS (Cantu, 2017). With SIS having heavy links to Alzheimer's and dementia in later life (Tator, 2013), particularly amongst ex-professional sports players who show weaker motor function and varying brain responses up to three decades after their last concussive episode (Beaumont et al., 2009), it is vitally important to understand the initial signs and symptoms of concussion and thus prevent SIS which may cause degenerative diseases later in life.

Many states across the United States have now made concussion education mandatory for players, parents, coaches and physicians of high school age grade sports teams (Tator, 2012). Literature has shown that through education and an increase in knowledge and understanding of concussion there can be a reduction in the number of incidences and improved outcomes (Goodman and Gaetz, 2002). The world of technology could help to educate many people online over a shorter time (Cook et al., 2003).

Some 52 journal articles, 20 websites and 2 books were reviewed within a qualitative literature review by Provvidenza and Johnston, (2009) on knowledge transfer and concussion education and showed that physicians' knowledge and performance are impacted by education outreach, interaction and reminder messages. Phillips et al., (2016) also suggested that online outreach programs, reminder messages printed on walls and interactions with specialists in neurology could potentially improve a physician's knowledge and understanding of concussion.

Adopting a different approach and using the knowledge gained within the sporting world may be something to review in the future whilst developing protocols within the NHS. Campaigns aimed around trying to educate parents and physicians across the UK and throughout the sporting world would be useful. Within the NHS Emergency Departments which still see the majority of national concussion cases, there needs to be further research into increasing the knowledge of the signs and symptoms of concussion for patients and physicians alike.

9.4 Conclusion

In this small study Junior Doctors performed no better than Professional Cricketers, Rugby Union Players and Rugby League Players in the ROCKSA-ST Concussion Attitudes Questionnaire. Improvement in physician training around the topic of concussion needs to be part of NHS continuous Medical Education. It is difficult to draw any real conclusion due to the lack of participation within the Junior Doctor group, however, further research across departments and hospital may be beneficial to enable a better understanding of the level of knowledge. These results could be compared to hospitals to set a baseline score that is required within an extra to pass an education module. With these areas being addressed if a professional player or public member is lacking in education around concussion and injuries, at least with a high level of knowledge within hospital department it could limit the risk of misdiagnosis and injuries getting missed altogether.

Chapter 10. Conclusions and Recommendations

The aim of this study was to analyse the use of baseline testing for improving the detection, education, and management of concussion in Professional County Cricket. Overall, this aim was achieved through various ways stated in the coming chapter. The originality of this study was very high, no other study has ever tried to use baseline testing to increase education in Professional Cricket, whilst also attempting to impact the diagnosis and management of concussion across a national governing body like the ECB. Furthermore, all baseline tests conducted were by non-medically qualified professionals showing that these tests could be conducted by anyone in any situation. Furthermore, this study also compared and contrasted various other sports in its findings, to allow future work to continue in a very wide and challenging Sports Medical area.

The objectives met throughout the study achieved within the Pilot study and the Multicenter study helped to conduct a survey of Professional Cricketers playing county cricket in England and to collect information on their playing history and details of any sport-related concussive episodes. Within chapter 7 the RoCKSA- ST questionnaire demonstrated how to establish cricketer's knowledge and understanding of concussion through a quantitative research analysis of questionnaires. With the objective to carry out baseline medical screening and establish baseline scores for a range of physical and psychological ability tests which was shown throughout chapters 5,6,8 and 9. The objective to correlate the experimental data producing a coherent analysis of all data sets allowing comparison of baseline scores, knowledge and understanding questionnaires and mental toughness questionnaires to find differences among test results and players characteristics was demonstrated throughout the thesis however, it was decided that the mental toughness questionnaire diverted from the true findings around levels of education and knowledge of concussion but could be considered in future research if deemed appropriate.

Within this study, the ability to perform a retrospective validation of the data collection and baseline testing protocols enabled rigorous testing of the model, and therefore testing the hypothesis 'Does baseline testing aid in the education of concussion within Professional Cricketers?' At the same time making use of appropriate statistical data from other sports such as Rugby Union and Rugby League as a comparison was shown throughout the methods and material sections of the thesis. This collection method was successfully completed by a team of non medically qualified personnel allowing the future of baseline testing to be opened up to the general population.

The work within this thesis attempted to answer "Does baseline-testing aid the diagnosis and/or alter the management of concussion for Professional Cricketers?" And "Does baseline testing facilitate and contribute to the knowledge and awareness of concussion among Professional Cricketers?" With all the work done throughout this research project and from a practical standpoint, it is fair to state that baseline testing has aided in the management of concussion for Professional Cricketers from a high level as the entire 18 professional counties took part and changed the way in which records of concussive episodes were collected and reviewed. However, this study does not truly answer the question whether or not non-invasive tests alter the diagnosis or management of a concussive episode in professional cricket, but there does seem to have been an impact on the increase of awareness in and around the use of baseline testing to aid in the diagnosis of a concussion, and its use in professional cricket.

Even though the research into whether it altered the management after a concussive episode is inconclusive, it is something that should be considered for future research, as this would also contribute to players returning from TBI.

Some 655 participants took part within the study, 186 were International players and 469 Professional County Cricketers (Table 6.5**)**. Some155 helmet strikes were seen during the study resulting in the diagnosis of 47 concussive episodes, and 347 missed days of training and match play (Table 6.2). Concussion rates over the 3-year study period decreased from 48% (2016), to 32% (2017) and 25% (2018) (Table 6.1). This may be due to an increase of correct concussion diagnoses due to baseline testing and better management of concussion from club physicians, however we cannot be certain this is the case.

Whilst this study was retrospective, it does demonstrate the number of maxillofacial injuries, concussive episodes and helmet strikes in Professional Cricketers over a specific period of time between 2016 and 2018. The findings suggest that in 2016 some 5 maxillofacial injuries occurred, with 5 in 2017 and 11 in 2018 (Table 3.1). These injuries ranged in severity from nose laceration (5%), scalp bruising (29%) and jaw bruising/ haematoma (19%). With a total of 155 helmet strikes between 2016-2018 and 47 concussive episodes (Table 4.1) resulting in a ratio of 3:1 helmet strikes to concussive episodes (Table 4.2). Furthermore, there is shown to be an increase between 2016-2018 in helmet strikes, with 23 helmet strikes in (2016), 38 helmet strikes in (2017) and 94 helmet strikes in (2018) which suggests that due to the baseline testing intervention, an increase in awareness about concussion has led to more helmet strikes being recognised.

However, the true concussion rate will only be able to be evaluated over a longer period of time. Match play saw the highest number of helmet strikes with 124 (82%) compared to 27 in training (18%) and 4 classed as other (Table 4.4). First team players had the highest number of helmet strikes by playing level. This would suggest that non-invasive and fast baseline testing, at first team level during match play could be beneficial to Professional Cricketers and physicians at diagnosing concussion.

The study shows an increase in mean scores on the RoCKSA-ST questionnaire between 2016-2018 (2016- 35.65, 2017- 36.38 and 2018- 36.66) with all the signs and symptoms being recognised more accurately between 2016-2018 (2%-6%) **(**Table 7.1). Although this does show an increase in awareness over the period of study, we are unable to say whether the Professional Cricketers may have had an increased understanding of concussion prior to baseline testing due to the media coverage around Phil Hughes tragic death. Furthermore, there was an increase in year 2 (2017) with the number of athletes answering the Signs and Symptoms (S&S) of concussion questionnaire correctly compared to year 1 (5% compared to 2%), suggesting an increase of understanding of S&S.

Between the years 2016-2018 there was a slight increase in the S&S compared to years 2016 -2017. Year 3 showed that 6% of athletes answered all S&S correctly and the average score for the RoCKSA-ST Concussion and Attitudes questionnaire increased to 36.66. However, this result was not significant (P= 0.547). When comparing year 2016-2018 there was still no significant difference despite a slightly improved significant difference (P=0.249).

The fact that there is no statistically significant difference in the relationships shown suggests further investigation is needed to demonstrate increases in levels of understanding. One compounding factor is that individuals may have taken time to improve their own education around the topic area.

This study also investigates whether professional cricket player's levels of knowledge around the topic area is greater or less when compared to Professional Rugby Union, Professional Rugby League players and Junior Doctors. There was no significant difference between the groups apart from in Sections 4 and 5 of the ROCKSA-ST questionnaire, where Rugby Union players significantly outscored Junior Doctors. Overall, there was no significant difference in the total scoring, and Junior Doctors did not demonstrate superior knowledge compared to the professional athletes.

The study showed that out of 144 male athletes from professional Rugby Union (contact sport) there was a large range in the STD and ranges in the baseline data. The normative data sets for playing position and level played will help guide general normative baseline testing. However, we are aware that this can be a time-consuming process but with the added benefit of an individual rehabilitation process post-concussion using objective markers. Without any objective markers the returning athlete may well take a longer time to make progresses from a concussive episode therefore exceeding the time it takes to gain a baseline score. Signs and symptoms (S&S) and knowledge at 24% needs addressing through widespread baseline testing and future research into levels of knowledge and attitudes. This would improve concussion diagnoses, reduce incorrect diagnoses, decrease Second Impact Syndrome (SIS) and reduce mental health issues later in life.

With concussion becoming only more topical through social media and ex-professional players taking legal action against national governing bodies, this study attempts to add to a wide range of research areas in Sport, Education and Concussion management. However, the foundation into baseline testing in professional sport could potentially help put the foundations for research into the general population and the management of concussion within the NHS and the knowledge and understanding of concussion across the NHS.

Specific recommendations for professional sports and the future research within concussion should take a more longitudinal approach over a 5 -10 year period to gain a more in depth understanding to whether there is a more serious issue around concussion within Professional Cricket in particular from Maxillofacial injuries, helmet strikes and education around concussion, tracking these longer term will enable a clearer picture. All elite sports have a duty of care towards the participants and with an increase in pressure all professional sports should be investigating concussion in more depth as we really are at the infancy of the topical area and they are at the very start of gaining a clearer picture of how to diagnose, rehabilitate and educate around the medical area of concussion. The hope for this study is that it will allow other researchers to move forward and shed light on this vast area that can leave so many athletes without a career, or worse, long term health issues.

This thesis has shown that not only is it possible to use baseline testing to help structure and educate teams across a national governing body, but it has also shown that many other sports and government services might need to research into the area of concussion and the level of knowledge and understanding. This thesis has also shown that we still really only understand the minimum amount about concussion even at an elite level.

Future research and interests

Mental toughness within sports is a key area that contributes to high performance. Within Professional Cricket even though a team sport it is still highly individual Batsmen have high levels of pressure and fatigue to endure during long test matches. The Mental Toughness and Anxiety 18-item self-reporting questionnaire (MTAQ) was also administered to assess the athlete's mental toughness levels with a maximum score of 90. This was not considered within the main thesis due to the need for further understanding around the area. Even though relevant within concussion due to the links between concussion and increase in feelings of anxiety post concussive episode it would be better placed within future research to enable a continuation into the link between concussion and mental toughness. For early findings please see below.

The MTAQ states that a score of less than 57 may be an indication of low mental toughness and would require further assessment by the club physicians. The mean score for the MTAQ was 66.76. This was produced from ranges of high mental toughness (70-90), medium mental toughness (58-69) and low mental toughness (18-57).

This study investigated the mental toughness levels of Professional Cricketers and Professional Rugby Union players. Professional Cricketers mean score on the MTAQ was 65.17/ 90 a highest score of 88/90 and a lowest score of 40/90 with a range of 48 with County level Cricketers having a higher mental toughness when compared to International Cricketers on average 65.5/90 to 64.29/90 The Professional Rugby Union players scored higher than the Professional Cricketers with a mean score on the MTAQ of 67.6/90 the highest score of 90/90 and a slightly lower score of 39/90 when compared to the Professional Cricketers and a slightly larger range of 51. However, international players outscored the Premiership and Championship players 69.7/90 compared to 67.4/90 and 67/90. No other findings have been demonstrated by the study and therefore further research into whether mental toughness impacts rehabilitation to be considered in future.

As it was stated, concussion is a very diverse and complex topic, which is still in its infancy of research, and the in-depth understanding of both the general public and physicians is unclear. Problems understanding the difference for an individual on what they perceive to be a concussion and what *is* an actual concussion arise, and may vary drastically from patient to patient, making it hard to quantify a concussive episode without previous diagnosis.

From a clinical perspective a retrospective study is never as strong as a retrospective study. With the high levels of participation 655 athletes in Professional Cricket it would be beneficial to increase the levels of participants from other sports and general population such as Rugby Union 61 athletes, Rugby League 64 athletes and 48 Junior doctors to see if a high significant value is found when comparing levels of knowledge and understanding within concussion. Future work also should include varying non-contact sports and allow a deeper understanding within the area to suggest whether non- contact sports have a lower levels of knowledge and understanding due to the limited amount of concussions they incur compared to contact sports such as Rugby Union and Rugby League.

Further limitations in regard to athlete compliance which was linked to the time-consuming process of the baseline testing. Time consuming processes ranged from trying to organise the screening day with each Country Cricket team to the distance travelled for each member of the research team sometimes led to limited numbers conducting the tests which in turn put pressure on the examiner of each test sometimes having to cover 2 stations. The entering of each data set from pen and paper was also a time-consuming process and in future should be automated.

It was observed but not documented some levels of dis engagement shown when participating within the study especially post training sessions. This leads me further to suggest that limitations around the physiological demands of training and potential fatigue impacting participant results. It was observed that baseline testing was conducted around the Professional Cricketers scheduling of training. However, this may have changed last minute due to teams changing training times without the research team been informed. Therefore, physiological fatigue may impact results such as SLBT, 9-peg hole, and KDT within future research it would be beneficial for teams to conduct baseline testing all at complete homeostatus level.

This is a retrospective study and a prospective study in how do baseline scores compare post concussive episode with mental toughness compared before and after injury would be not only interesting but beneficial for future guidance in the limited research in and around the rehabilitation processes from a concussive episode and could help guide the RTP process throughout all sports. Due to the limitations of the study not all the tests could be taken pitch side and the player had to be removed into the physician's medical room. However, the comparison between pitch side baseline testing and inside would be of interest to many partitioners due to the pressure of time to test the players and see if they are able to carry on participating in the match or training. This is seen throughout many sports such as Professional Cricket, Rugby Union and Rugby League where they have a HIA removal system for a 15-minute window to assess whether a player can return or not to the field during match play.

Results have shown normative data sets found for Professional Cricketers at varying levels within baseline testing leading to further hypothesising These may have meant they lacked in-depth knowledge in the area of such things as signs and symptoms, leading to miss self-diagnosis of a concussion within the past. However, further investigation is needed to obtain the reason for lack of knowledge.

Appendices

Appendices 1 General information form

NAME	
HEIGHT	
AGE	
NATIONALITY	
Batsman, Bowler, Wicketkeeper, Allrounder	
NUMBER OF YEARS AS A PROFESSIONAL	
NUMBER OF YEARS PLAYING CRICKET TOTAL	
HIGHEST LEVEL PLAYED	
NUMBER OF CONCUSSIONS	

BP	
PULSE	
HEART SOUNDS	
CHEST	
HERNIA	
DEPRESSION	
ANXIETY	
HEADACHES	
LETHARGY	

Appendices 2 Nationalities of players and participants

British	599
Australian	16
South African	16
New Zealand	5
Sri Lankan	1
Irish	7
Dutch	4
Bermudian	1
Russian	2
Zimbabwe	1
Barbadian	1
Guyanses	1

*1 participant unknown

Appendices 3 Scat 5 test

BJSM Online First, published on April 26, 2017 as 10.1136/bjsports-2017-097506SCAT5

To download a clean version of the SCAT tools please visit the journal online (http://dx.doi .org/10.1136/bjsports-2017-097506SCAT5)

SCAT5©

SPORT CONCUSSION ASSESSMENT TOOL — 5TH EDITION

DEVELOPED BY THE CONCUSSION IN SPORT GROUP

FOR USE BY MEDICAL PROFESSIONALS ONLY

supported by

FIFA® FEI

Patient details

Name: ______________________________

DOB: ______________________________

Address: ______________________________

ID number: ______________________________

Examiner: ______________________________

Date of Injury: ________________ Time: ________________

WHAT IS THE SCAT5?

The SCAT5 is a standardized tool for evaluating concussions designed for use by physicians and licensed healthcare professionals[1]. The SCAT5 cannot be performed correctly in less than 10 minutes.

If you are not a physician or licensed healthcare professional, please use the Concussion Recognition Tool 5 (CRT5). The SCAT5 is to be used for evaluating athletes aged 13 years and older. For children aged 12 years or younger, please use the Child SCAT5.

Preseason SCAT5 baseline testing can be useful for interpreting post-injury test scores, but is not required for that purpose.Detailed instructions for use of the SCAT5 are provided on page 7. Please read through these instructions carefully before testing the athlete. Brief verbal instructions for each test are given in italics. The only equipment required for the tester is a watch or timer.

This tool may be freely copied in its current form for distribution to individuals, teams, groups and organizations. It should not be altered in any way, re-branded or sold for commercial gain. Any revision, translation or reproduction in a digital form requires specific approval by the Concussion in Sport Group.

Recognise and Remove

A head impact by either a direct blow or indirect transmission of force can be associated with a serious and potentially fatal brain injury. If there are significant concerns, including any of the red flags listed in Box 1, then activation of emergency procedures and urgent transport to the nearest hospital should be arranged.

Key points

- Any athlete with suspected concussion should be REMOVED FROM PLAY, medically assessed and monitored for deterioration. No athlete diagnosed with concussion should be returned to play on the day of injury.
- If an athlete is suspected of having a concussion and medical personnel are not immediately available, the athlete should be referred to a medical facility for urgent assessment.
- Athletes with suspected concussion should not drink alcohol, use recreational drugs and should not drive a motor vehicle until cleared to do so by a medical professional.
- Concussion signs and symptoms evolve over time and it is important to consider repeat evaluation in the assessment of concussion.
- The diagnosis of a concussion is a clinical judgment, made by a medical professional. The SCAT5 should NOT be used by itself to make, or exclude, the diagnosis of concussion. An athlete may have a concussion even if their SCAT5 is "normal".

Remember:

- The basic principles of first aid (danger, response, airway, breathing, circulation) should be followed.
- Do not attempt to move the athlete (other than that required for airway management) unless trained to do so.
- Assessment for a spinal cord injury is a critical part of the initial on-field assessment.
- Do not remove a helmet or any other equipment unless trained to do so safely.

Davis GA, et al. Br J Sports Med 2017;0:1–8. doi:10.1136/bjsports-2017-097506SCAT5

1

IMMEDIATE OR ON-FIELD ASSESSMENT

The following elements should be assessed for all athletes who are suspected of having a concussion prior to proceeding to the neurocognitive assessment and ideally should be done on-field after the first first aid / emergency care priorities are completed.

If any of the "Red Flags" or observable signs are noted after a direct or indirect blow to the head, the athlete should be immediately and safely removed from participation and evaluated by a physician or licensed healthcare professional.

Consideration of transportation to a medical facility should be at the discretion of the physician or licensed healthcare professional.

The GCS is important as a standard measure for all patients and can be done serially if necessary in the event of deterioration in conscious state. The Maddocks questions and cervical spine exam are critical steps of the immediate assessment; however, these do not need to be done serially.

STEP 1: RED FLAGS

RED FLAGS:

- Neck pain or tenderness
- Double vision
- Weakness or tingling/ burning in arms or legs
- Severe or increasing headache
- Seizure or convulsion
- Loss of consciousness
- Deteriorating conscious state
- Vomiting
- Increasingly restless, agitated or combative

STEP 2: OBSERVABLE SIGNS

Witnessed ☐ Observed on Video ☐

Lying motionless on the playing surface	Y	N
Balance / gait difficulties / motor incoordination: stumbling, slow / laboured movements	Y	N
Disorientation or confusion, or an inability to respond appropriately to questions	Y	N
Blank or vacant look	Y	N
Facial injury after head trauma	Y	N

STEP 3: MEMORY ASSESSMENT MADDOCKS QUESTIONS[2]

"I am going to ask you a few questions, please listen carefully and give your best effort. First, tell me what happened?"

Mark Y for correct answer / N for incorrect

What venue are we at today?	Y	N
Which half is it now?	Y	N
Who scored last in this match?	Y	N
What team did you play last week / game?	Y	N
Did your team win the last game?	Y	N

Note: Appropriate sport-specific questions may be substituted.

Name: __________

DOB: __________

Address: __________

ID number: __________

Examiner: __________

Date: __________

STEP 4: EXAMINATION GLASGOW COMA SCALE (GCS)[3]

Time of assessment			
Date of assessment			
Best eye response (E)			
No eye opening	1	1	1
Eye opening in response to pain	2	2	2
Eye opening to speech	3	3	3
Eyes opening spontaneously	4	4	4
Best verbal response (V)			
No verbal response	1	1	1
Incomprehensible sounds	2	2	2
Inappropriate words	3	3	3
Confused	4	4	4
Oriented	5	5	5
Best motor response (M)			
No motor response	1	1	1
Extension to pain	2	2	2
Abnormal flexion to pain	3	3	3
Flexion / Withdrawal to pain	4	4	4
Localizes to pain	5	5	5
Obeys commands	6	6	6
Glasgow Coma score (E + V + M)			

CERVICAL SPINE ASSESSMENT

Does the athlete report that their neck is pain free at rest?	Y	N
If there is NO neck pain at rest, does the athlete have a full range of ACTIVE pain free movement?	Y	N
Is the limb strength and sensation normal?	Y	N

In a patient who is not lucid or fully conscious, a cervical spine injury should be assumed until proven otherwise.

OFFICE OR OFF-FIELD ASSESSMENT

Please note that the neurocognitive assessment should be done in a distraction-free environment with the athlete in a resting state.

STEP 1: ATHLETE BACKGROUND

Sport / team / school: ____________________

Date / time of injury: ____________________

Years of education completed: ____________________

Age: ____________________

Gender: M / F / Other

Dominant hand: left / neither / right

How many diagnosed concussions has the athlete had in the past?: ____________________

When was the most recent concussion?: ____________________

How long was the recovery (time to being cleared to play) from the most recent concussion?: ____________ (days)

Has the athlete ever been:

Hospitalized for a head injury?	Yes	No
Diagnosed / treated for headache disorder or migraines?	Yes	No
Diagnosed with a learning disability / dyslexia?	Yes	No
Diagnosed with ADD / ADHD?	Yes	No
Diagnosed with depression, anxiety or other psychiatric disorder?	Yes	No

Current medications? If yes, please list:

____

____

____

____

____

____

Name: ____________________

DOB: ____________________

Address: ____________________

ID number: ____________________

Examiner: ____________________

Date: ____________________

2

STEP 2: SYMPTOM EVALUATION

The athlete should be given the symptom form and asked to read this instruction paragraph out loud then complete the symptom scale. For the baseline assessment, the athlete should rate his/her symptoms based on how he/she typically feels and for the post injury assessment the athlete should rate their symptoms at this point in time.

Please Check: ☐ Baseline ☐ Post-Injury

Please hand the form to the athlete

	none	mild		moderate		severe	
Headache	0	1	2	3	4	5	6
"Pressure in head"	0	1	2	3	4	5	6
Neck Pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like "in a fog"	0	1	2	3	4	5	6
"Don't feel right"	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or Anxious	0	1	2	3	4	5	6
Trouble falling asleep (if applicable)	0	1	2	3	4	5	6

Total number of symptoms:	of 22
Symptom severity score:	of 132
Do your symptoms get worse with physical activity?	Y N
Do your symptoms get worse with mental activity?	Y N
If 100% is feeling perfectly normal, what percent of normal do you feel?	

If not 100%, why?

____

____

____

Please hand form back to examiner

3

STEP 3: COGNITIVE SCREENING

Standardised Assessment of Concussion (SAC)[4]

ORIENTATION

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
What time is it right now? (within 1 hour)	0	1
Orientation score		of 5

IMMEDIATE MEMORY

The Immediate Memory component can be completed using the traditional 5-word per trial list or optionally using 10-words per trial to minimise any ceiling effect. All 3 trials must be administered irrespective of the number correct on the first trial. Administer at the rate of one word per second.

Please choose EITHER the 5 or 10 word list groups and circle the specific word list chosen for this test.

I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order. For Trials 2 & 3: I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before.

List	Alternate 5 word lists					Score (of 5) Trial 1	Trial 2	Trial 3
A	Finger	Penny	Blanket	Lemon	Insect			
B	Candle	Paper	Sugar	Sandwich	Wagon			
C	Baby	Monkey	Perfume	Sunset	Iron			
D	Elbow	Apple	Carpet	Saddle	Bubble			
E	Jacket	Arrow	Pepper	Cotton	Movie			
F	Dollar	Honey	Mirror	Saddle	Anchor			
					Immediate Memory Score	of 15		
					Time that last trial was completed			

List	Alternate 10 word lists					Score (of 10) Trial 1	Trial 2	Trial 3
G	Finger	Penny	Blanket	Lemon	Insect			
	Candle	Paper	Sugar	Sandwich	Wagon			
H	Baby	Monkey	Perfume	Sunset	Iron			
	Elbow	Apple	Carpet	Saddle	Bubble			
I	Jacket	Arrow	Pepper	Cotton	Movie			
	Dollar	Honey	Mirror	Saddle	Anchor			
					Immediate Memory Score	of 30		
					Time that last trial was completed			

Name: __________
DOB: __________
Address: __________
ID number: __________
Examiner: __________
Date: __________

CONCENTRATION

DIGITS BACKWARDS

Please circle the Digit list chosen (A, B, C, D, E, F). Administer at the rate of one digit per second reading DOWN the selected column.

I am going to read a string of numbers and when I am done, you repeat them back to me in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7.

Concentration Number Lists (circle one)

List A	List B	List C			
4-9-3	5-2-6	1-4-2	Y	N	0
6-2-9	4-1-5	6-5-8	Y	N	1
3-8-1-4	1-7-9-5	6-8-3-1	Y	N	0
3-2-7-9	4-9-6-8	3-4-8-1	Y	N	1
6-2-9-7-1	4-8-5-2-7	4-9-1-5-3	Y	N	0
1-5-2-8-6	6-1-8-4-3	6-8-2-5-1	Y	N	1
7-1-8-4-6-2	8-3-1-9-6-4	3-7-6-5-1-9	Y	N	0
5-3-9-1-4-8	7-2-4-8-5-6	9-2-6-5-1-4	Y	N	1
List D	**List E**	**List F**			
7-8-2	3-8-2	2-7-1	Y	N	0
9-2-6	5-1-8	4-7-9	Y	N	1
4-1-8-3	2-7-9-3	1-6-8-3	Y	N	0
9-7-2-3	2-1-6-9	3-9-2-4	Y	N	1
1-7-9-2-6	4-1-8-6-9	2-4-7-5-8	Y	N	0
4-1-7-5-2	9-4-1-7-5	8-3-9-6-4	Y	N	1
2-6-4-8-1-7	6-9-7-3-8-2	5-8-6-2-4-9	Y	N	0
8-4-1-9-3-5	4-2-7-9-3-8	3-1-7-8-2-6	Y	N	1
		Digits Score:			of 4

MONTHS IN REVERSE ORDER

Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November. Go ahead.

Dec - Nov - Oct - Sept - Aug - Jul - Jun - May - Apr - Mar - Feb - Jan	0 1
Months Score	of 1
Concentration Total Score (Digits + Months)	of 5

4

STEP 4: NEUROLOGICAL SCREEN

See the instruction sheet (page 7) for details of test administration and scoring of the tests.

Can the patient read aloud (e.g. symptom check-list) and follow instructions without difficulty?	Y	N
Does the patient have a full range of pain-free PASSIVE cervical spine movement?	Y	N
Without moving their head or neck, can the patient look side-to-side and up-and-down without double vision?	Y	N
Can the patient perform the finger nose coordination test normally?	Y	N
Can the patient perform tandem gait normally?	Y	N

BALANCE EXAMINATION

Modified Balance Error Scoring System (mBESS) testing[5]

Which foot was tested (i.e. which is the non-dominant foot) ☐ Left ☐ Right

Testing surface (hard floor, field, etc.) ___________

Footwear (shoes, barefoot, braces, tape, etc.) ___________

Condition	Errors
Double leg stance	of 10
Single leg stance (non-dominant foot)	of 10
Tandem stance (non-dominant foot at the back)	of 10
Total Errors	of 30

Name: ___________

DOB: ___________

Address: ___________

ID number: ___________

Examiner: ___________

Date: ___________

5

STEP 5: DELAYED RECALL:

The delayed recall should be performed after 5 minutes have elapsed since the end of the Immediate Recall section. Score 1 pt. for each correct response.

Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order.

Time Started ___________

Please record each word correctly recalled. Total score equals number of words recalled.

____

____

____

Total number of words recalled accurately: of 5 or of 10

6

STEP 6: DECISION

Domain	Date & time of assessment:		
Symptom number (of 22)			
Symptom severity score (of 132)			
Orientation (of 5)			
Immediate memory	of 15 of 30	of 15 of 30	of 15 of 30
Concentration (of 5)			
Neuro exam	Normal Abnormal	Normal Abnormal	Normal Abnormal
Balance errors (of 30)			
Delayed Recall	of 5 of 10	of 5 of 10	of 5 of 10

Date and time of injury: ___________

If the athlete is known to you prior to their injury, are they different from their usual self?
☐ **Yes** ☐ **No** ☐ **Unsure** ☐ **Not Applicable**
(If different, describe why in the clinical notes section)

Concussion Diagnosed?
☐ **Yes** ☐ **No** ☐ **Unsure** ☐ **Not Applicable**

If re-testing, has the athlete improved?
☐ **Yes** ☐ **No** ☐ **Unsure** ☐ **Not Applicable**

I am a physician or licensed healthcare professional and I have personally administered or supervised the administration of this SCAT5.

Signature: ___________

Name: ___________

Title: ___________

Registration number (if applicable): ___________

Date: ___________

SCORING ON THE SCAT5 SHOULD NOT BE USED AS A STAND-ALONE METHOD TO DIAGNOSE CONCUSSION, MEASURE RECOVERY OR MAKE DECISIONS ABOUT AN ATHLETE'S READINESS TO RETURN TO COMPETITION AFTER CONCUSSION.

CLINICAL NOTES:

Name: ____________________
DOB: ____________________
Address: ____________________
ID number: ____________________
Examiner: ____________________
Date: ____________________

CONCUSSION INJURY ADVICE

(To be given to the person monitoring the concussed athlete)

This patient has received an injury to the head. A careful medical examination has been carried out and no sign of any serious complications has been found. Recovery time is variable across individuals and the patient will need monitoring for a further period by a responsible adult. Your treating physician will provide guidance as to this timeframe.

If you notice any change in behaviour, vomiting, worsening headache, double vision or excessive drowsiness, please telephone your doctor or the nearest hospital emergency department immediately.

Other important points:

Initial rest: Limit physical activity to routine daily activities (avoid exercise, training, sports) and limit activities such as school, work, and screen time to a level that does not worsen symptoms.

1) Avoid alcohol

2) Avoid prescription or non-prescription drugs without medical supervision. Specifically:

a) Avoid sleeping tablets

b) Do not use aspirin, anti-inflammatory medication or stronger pain medications such as narcotics

3) Do not drive until cleared by a healthcare professional.

4) Return to play/sport requires clearance by a healthcare professional.

Clinic phone number: ____________________

Patient's name: ____________________

Date / time of injury: ____________________

Date / time of medical review: ____________________

Healthcare Provider: ____________________

Contact details or stamp

CLINICAL NOTES:

Name: ______
DOB: ______
Address: ______
ID number: ______
Examiner: ______
Date: ______

CONCUSSION INJURY ADVICE

(To be given to the person monitoring the concussed athlete)

This patient has received an injury to the head. A careful medical examination has been carried out and no sign of any serious complications has been found. Recovery time is variable across individuals and the patient will need monitoring for a further period by a responsible adult. Your treating physician will provide guidance as to this timeframe.

If you notice any change in behaviour, vomiting, worsening headache, double vision or excessive drowsiness, please telephone your doctor or the nearest hospital emergency department immediately.

Other important points:

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4) Return to play/sport requires clearance by a healthcare professional.

Clinic phone number: ______

Patient's name: ______

Date / time of injury: ______

Date / time of medical review: ______

Healthcare Provider: ______

Contact details or stamp

CONCUSSION INFORMATION

Any athlete suspected of having a concussion should be removed from play and seek medical evaluation.

Signs to watch for

Problems could arise over the first 24-48 hours. The athlete should not be left alone and must go to a hospital at once if they experience:

- Worsening headache
- Drowsiness or inability to be awakened
- Inability to recognize people or places
- Repeated vomiting
- Unusual behaviour or confusion or irritable
- Seizures (arms and legs jerk uncontrollably)
- Weakness or numbness in arms or legs
- Unsteadiness on their feet.
- Slurred speech

Consult your physician or licensed healthcare professional after a suspected concussion. Remember, it is better to be safe.

Rest & Rehabilitation

After a concussion, the athlete should have physical rest and relative cognitive rest for a few days to allow their symptoms to improve. In most cases, after no more than a few days of rest, the athlete should gradually increase their daily activity level as long as their symptoms do not worsen. Once the athlete is able to complete their usual daily activities without concussion-related symptoms, the second step of the return to play/sport progression can be started. The athlete should not return to play/sport until their concussion-related symptoms have resolved and the athlete has successfully returned to full school/learning activities.

When returning to play/sport, the athlete should follow a stepwise, **medically managed exercise progression, with increasing amounts of exercise.** For example:

Graduated Return to Sport Strategy

Exercise step	Functional exercise at each step	Goal of each step
1. Symptom-limited activity	Daily activities that do not provoke symptoms.	Gradual reintroduction of work/school activities.
2. Light aerobic exercise	Walking or stationary cycling at slow to medium pace. No resistance training.	Increase heart rate.
3. Sport-specific exercise	Running or skating drills. No head impact activities.	Add movement.
4. Non-contact training drills	Harder training drills, e.g., passing drills. May start progressive resistance training.	Exercise, coordination, and increased thinking.
5. Full contact practice	Following medical clearance, participate in normal training activities.	Restore confidence and assess functional skills by coaching staff.
6. Return to play/sport	Normal game play.	

In this example, it would be typical to have 24 hours (or longer) for each step of the progression. If any symptoms worsen while exercising, the athlete should go back to the previous step. Resistance training should be added only in the later stages (Stage 3 or 4 at the earliest).

Written clearance should be provided by a healthcare professional before return to play/sport as directed by local laws and regulations.

Graduated Return to School Strategy

Concussion may affect the ability to learn at school. The athlete may need to miss a few days of school after a concussion. When going back to school, some athletes may need to go back gradually and may need to have some changes made to their schedule so that concussion symptoms do not get worse. If a particular activity makes symptoms worse, then the athlete should stop that activity and rest until symptoms get better. To make sure that the athlete can get back to school without problems, it is important that the healthcare provider, parents, caregivers and teachers talk to each other so that everyone knows what the plan is for the athlete to go back to school.

Note: If mental activity does not cause any symptoms, the athlete may be able to skip step 2 and return to school part-time before doing school activities at home first.

Mental Activity	Activity at each step	Goal of each step
1. Daily activities that do not give the athlete symptoms	Typical activities that the athlete does during the day as long as they do not increase symptoms (e.g. reading, texting, screen time). Start with 5-15 minutes at a time and gradually build up.	Gradual return to typical activities.
2. School activities	Homework, reading or other cognitive activities outside of the classroom.	Increase tolerance to cognitive work.
3. Return to school part-time	Gradual introduction of schoolwork. May need to start with a partial school day or with increased breaks during the day.	Increase academic activities.
4. Return to school full-time	Gradually progress school activities until a full day can be tolerated.	Return to full academic activities and catch up on missed work.

If the athlete continues to have symptoms with mental activity, some other accomodations that can help with return to school may include:

- Starting school later, only going for half days, or going only to certain classes
- More time to finish assignments/tests
- Quiet room to finish assignments/tests
- Not going to noisy areas like the cafeteria, assembly halls, sporting events, music class, shop class, etc.
- Taking lots of breaks during class, homework, tests
- No more than one exam/day
- Shorter assignments
- Repetition/memory cues
- Use of a student helper/tutor
- Reassurance from teachers that the child will be supported while getting better

The athlete should not go back to sports until they are back to school/learning, without symptoms getting significantly worse and no longer needing any changes to their schedule.

INSTRUCTIONS

Words in *Italics* throughout the SCAT5 are the instructions given to the athlete by the clinician

Symptom Scale

The time frame for symptoms should be based on the type of test being administered. At baseline it is advantageous to assess how an athlete "typically" feels whereas during the acute/post-acute stage it is best to ask how the athlete feels at the time of testing.

The symptom scale should be completed by the athlete, not by the examiner. In situations where the symptom scale is being completed after exercise, it should be done in a resting state, generally by approximating his/her resting heart rate.

For total number of symptoms, maximum possible is 22 except immediately post injury, if sleep item is omitted, which then creates a maximum of 21.

For Symptom severity score, add all scores in table, maximum possible is 22 x 6 = 132, except immediately post injury if sleep item is omitted, which then creates a maximum of 21x6=126.

Immediate Memory

The Immediate Memory component can be completed using the traditional 5-word per trial list or, optionally, using 10-words per trial. The literature suggests that the Immediate Memory has a notable ceiling effect when a 5-word list is used. In settings where this ceiling is prominent, the examiner may wish to make the task more difficult by incorporating two 5–word groups for a total of 10 words per trial. In this case, the maximum score per trial is 10 with a total trial maximum of 30.

Choose one of the word lists (either 5 or 10). Then perform 3 trials of immediate memory using this list.

Complete all 3 trials regardless of score on previous trials.

"I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order." The words must be read at a rate of one word per second.

Trials 2 & 3 MUST be completed regardless of score on trial 1 & 2.

Trials 2 & 3:

"I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before."

Score 1 pt. for each correct response. Total score equals sum across all 3 trials. Do NOT inform the athlete that delayed recall will be tested.

Concentration

Digits backward

Choose one column of digits from lists A, B, C, D, E or F and administer those digits as follows:

Say: *"I am going to read a string of numbers and when I am done, you repeat them back to me in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7."*

Begin with first 3 digit string.

If correct, circle "Y" for correct and go to next string length. If incorrect, circle "N" for the first string length and read trial 2 in the same string length. One point possible for each string length. Stop after incorrect on both trials (2 N's) in a string length. The digits should be read at the rate of one per second.

Months in reverse order

"Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November ... Go ahead"

1 pt. for entire sequence correct

Delayed Recall

The delayed recall should be performed after 5 minutes have elapsed since the end of the Immediate Recall section.

"Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order."

Score 1 pt. for each correct response

Modified Balance Error Scoring System (mBESS)[5] testing

This balance testing is based on a modified version of the Balance Error Scoring System (BESS)[5]. A timing device is required for this testing.

Each of 20-second trial/stance is scored by counting the number of errors. The examiner will begin counting errors only after the athlete has assumed the proper start position. The modified BESS is calculated by adding one error point for each error during the three 20-second tests. The maximum number of errors for any single condition is 10. If the athlete commits multiple errors simultaneously, only one error is recorded but the athlete should quickly return to the testing position, and counting should resume once the athlete is set. Athletes that are unable to maintain the testing procedure for a minimum of five seconds at the start are assigned the highest possible score, ten, for that testing condition.

OPTION: For further assessment, the same 3 stances can be performed on a surface of medium density foam (e.g., approximately 50cm x 40cm x 6cm).

Balance testing – types of errors

1. Hands lifted off iliac crest
2. Opening eyes
3. Step, stumble, or fall
4. Moving hip into > 30 degrees abduction
5. Lifting forefoot or heel
6. Remaining out of test position > 5 sec

"I am now going to test your balance. Please take your shoes off (if applicable), roll up your pant legs above ankle (if applicable), and remove any ankle taping (if applicable). This test will consist of three twenty second tests with different stances."

(a) Double leg stance:

"The first stance is standing with your feet together with your hands on your hips and with your eyes closed. You should try to maintain stability in that position for 20 seconds. I will be counting the number of times you move out of this position. I will start timing when you are set and have closed your eyes."

(b) Single leg stance:

"If you were to kick a ball, which foot would you use? [This will be the dominant foot] *Now stand on your non-dominant foot. The dominant leg should be held in approximately 30 degrees of hip flexion and 45 degrees of knee flexion. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."*

(c) Tandem stance:

"Now stand heel-to-toe with your non-dominant foot in back. Your weight should be evenly distributed across both feet. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."

Tandem Gait

Participants are instructed to stand with their feet together behind a starting line (the test is best done with footwear removed). Then, they walk in a forward direction as quickly and as accurately as possible along a 38mm wide (sports tape), 3 metre line with an alternate foot heel-to-toe gait ensuring that they approximate their heel and toe on each step. Once they cross the end of the 3m line, they turn 180 degrees and return to the starting point using the same gait. Athletes fail the test if they step off the line, have a separation between their heel and toe, or if they touch or grab the examiner or an object.

Finger to Nose

"I am going to test your coordination now. Please sit comfortably on the chair with your eyes open and your arm (either right or left) outstretched (shoulder flexed to 90 degrees and elbow and fingers extended), pointing in front of you. When I give a start signal, I would like you to perform five successive finger to nose repetitions using your index finger to touch the tip of the nose, and then return to the starting position, as quickly and as accurately as possible."

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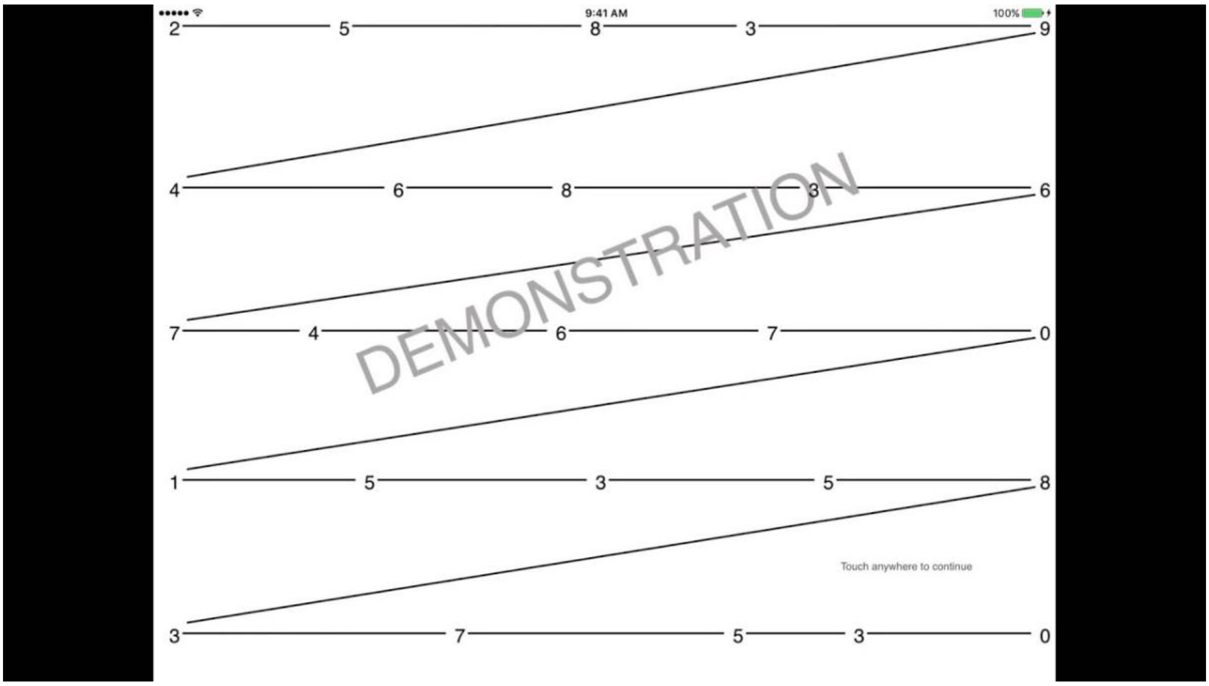
5. Guskiewicz KM. Assessment of postural stability following sport-related concussion. Current Sports Medicine Reports. 2003; 2: 24-30

Appendices 4 9-peg hole test

Appendices 5 King Devick test (Screen shot)

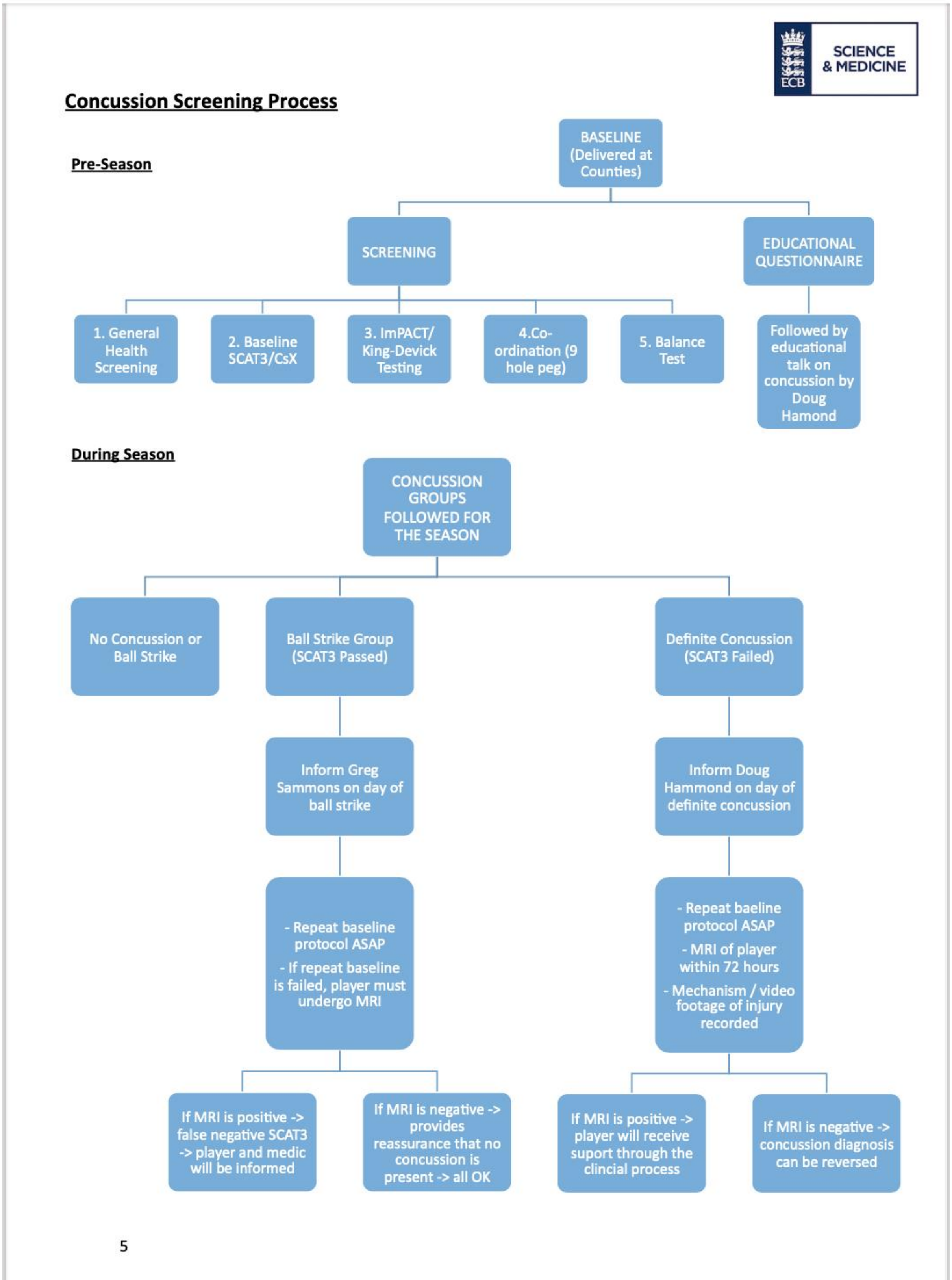


Appendices 6 Single leg balance test

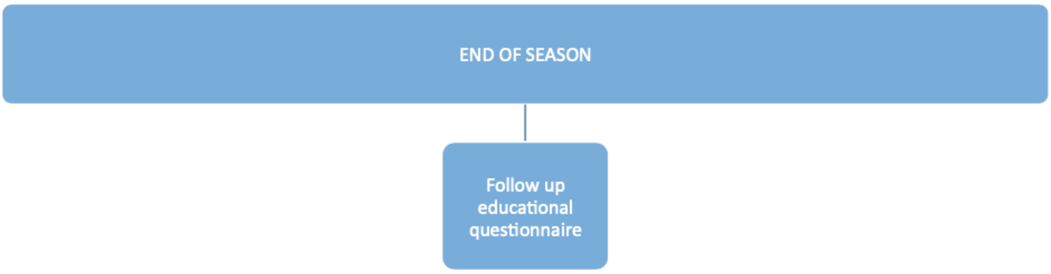
Appendices 7 Impact computer Test

Appendices 8 Front over of research manual for ECB

Appendices 9 Diagram of concussion screening process



End of Season



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