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The Challenges of Concussion Assessment, Management and Education within UK Youth Community Rugby Union

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# The Challenges of Concussion Assessment, Management and Education within UK Youth Community Rugby Union

by

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**May 2023**

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## Table of Contents

**DECLARATION** 2
**ACKNOWLEDGMENTS** 3
**LIST OF FIGURES** 7
**LIST OF TABLES** 10
**LIST OF PUBLICATIONS** 11
**ABSTRACT** 12
**Chapter One** 13
*1.0 Thesis Introduction* 13
*1.1 Concussion in Rugby Union* 13
*1.2 Youth Rugby Concussion Context* 15
1.2.1 Concussion Definition 18
1.2.2 Pitch-side Assessment Inconsistency 19
1.2.3 Assessment Tool Limitations 20
1.2.4 Limited Player Knowledge and Attitude Understanding 22
1.2.5 Non-validated Risk Reduction Strategies 22
1.2.6 Thesis Origins 25
*1.3 Summary* 27
*1.4 Thesis Aims* 29
*1.5 Thesis Structure* 30
**Chapter Two** 33
*2.0 Literature Review* 33
*2.1 Literature Review Introduction* 33
*2.2 Pathophysiology of Mild Traumatic Brain Injury (mTBI)* 34
2.2.1 Diffuse Axonal Injury (DAI) 34
2.2.2 Neuro-metabolic Cascade 36
2.2.3 Potassium & Glucose 36
2.2.4 Cerebral Blood Flow 37
2.2.5 Calcium 37
2.2.6 Mitochondrial Dysfunction 39
2.2.7 Neuro-inflammation/Microglial activation 39
*2.3 Biomechanics* 40
2.3.1 Physical Forces 40
2.3.2 Kinematics 41
*2.4 Symptoms* 48
2.4.1 Memory Disruption 50
2.4.2 Neuro-Cognitive Function 52
2.4.3 Spatio-Temporal Impairments 55
2.4.4 Mathematical difficulties 55
2.4.5 Cognitive-Linguistic Deficits 56
2.4.6 Headache 56
2.4.7 Balance Disturbance and Gait Disruption 59
2.4.8 Loss of Consciousness 60
2.4.9 Occulo-motor Disturbance 62
2.4.10 Other Symptoms 62
*2.5 Risk Factors* 63
2.5.1 Sex Differences 63
2.5.2 Age 65
2.5.3 Genetics 66
2.5.4 Learning Difficulties 67
2.5.5 Previous Concussion 68
2.5.6 Neck Strength 69
2.5.7 Sport Type 72
2.5.8 Rugby Specific Risk 74
2.5.9 Rugby Headgear 82
2.5.10 Rugby Contact Nature 83

*2.6 Assessment* ... *89*
2.6.1 Biomarkers ... 89
2.6.2 Diagnostic Imaging ... 93
2.6.3 Neuro-psychological/Physical ... 97
2.6.4 Standardised Assessment of Concussion (SAC) ... 100
2.6.5 Balance/Vestibular assessment ... 102
2.6.6 Coordination ... 105
2.6.7 Sports Concussion Assessment Tool (SCAT) ... 105
2.6.8 Computer Based Assessments ... 110
2.6.9 Head Injury Assessment (HIA) ... 111
2.6.10 Occulo-motor Assessment ... 115
2.6.11 The King-Devick Test ... 120
*2.7 Stakeholder Role, Knowledge and Attitudes* ... *127*
2.7.1 Parents ... 127
2.7.2 Knowledge ... 128
2.7.3 Attitudes ... 130
2.7.4 Perceived Role ... 134
2.7.5 Players ... 138
2.7.6 Player Knowledge ... 138
2.7.7 Player Attitudes ... 142
*2.8 Rugby Concussion Risk Reduction* ... *170*
2.8.1 Rugby Concussion Education ... 170
2.8.2 New Zealand - RugbySmart ... 171
2.8.3 South Africa - BokSmart ... 173
2.8.4 England – 'Don't be a HEADCASE' ... 176
2.8.5 Education Evaluation ... 178
2.8.6 Neck Strengthening ... 179
2.8.7 Game Characteristics ... 180
2.8.8 Risk Reduction Directions ... 174
*2.9 Literature Review Conclusions* ... *180*
**Chapter Three** ... **183**
STUDY ONE ... 183
*3.0 Overview* ... *183*
*3.1 Introduction* ... *183*
*3.2 Aim* ... *186*
*3.3 Method* ... *186*
3.3.1 Participants ... 186
3.3.2 Procedure ... 188
*3.4 Results* ... *191*
3.4.1 Baseline Data ... 191
3.4.2 Head Injuries ... 192
*3.5 Discussion* ... *196*
3.5.1 Baseline Data ... 196
3.5.2 Reported Head Injuries ... 197
3.5.3 Post Injury Assessment ... 199
3.5.3 Parent Directed Assessment ... 200
*3.5 Limitations* ... *202*
*3.6 Conclusion* ... *203*
**Chapter Four** ... **205**
STUDY TWO. ... 205
*4.0 Overview* ... *205*
*4.1 Introduction* ... *205*
*4.2 Aim* ... *208*
*4.3 Methods* ... *209*
4.3.1 Setting ... 209
4.3.2 Participants ... 209
4.3.3 Interview ... 210
4.3.4 Data Analysis ... 212
*4.4 Results* ... *212*
4.4.1 Demographics, Participation and Education ... 212
4.4.2 Role and Responsibilities ... 214

*4.5 Discussion* ... *222*
4.5.1 Demographics and Understanding of Concussion Management ... 222
4.5.2 Perceived Roles and Responsibilities Within Concussion Management ... 224
*4.6 Limitations* ... *227*
*4.7 Conclusion* ... *227*
**Chapter Five ... 229**
STUDY THREE ... 229
*5.0 Overview* ... *229*
*5.1 Introduction* ... *230*
*5.2 Methods* ... *234*
5.2.1 Recruitment ... 234
5.2.2 Participants ... 235
5.2.3 Data Collection ... 235
5.2.4 Data Handling ... 238
5.2.5 Data analysis ... 239
*5.3 Results* ... *239*
5.3.1 Demographic Information ... 239
5.3.2 Concussion Knowledge Index ... 243
5.3.3 Concussion Knowledge Themes ... 245
5.3.4 Concussion Knowledge Questions ... 252
5.3.5 Concussion Attitude Index ... 254
5.3.6 Concussion Attitude Themes ... 256
5.3.7 Concussion Attitude Statements ... 268
5.3.8 Concussion Knowledge and Attitude Associations ... 271
*5.4 Discussion* ... *272*
5.4.1 Concussion Knowledge ... 274
5.4.2 Concussion Attitude ... 275
5.4.3 Sex Differences ... 280
5.4.4 School Attendance ... 281
5.4.5 Age and Experience ... 282
5.4.6 Concussion Knowledge and Attitude Associations ... 283
*5.6 Limitations* ... *284*
*5.7 Recommendations for Educational Strategies* ... *286*
*5.8 Conclusions* ... *287*
**Chapter Six ... 289**
*6.0 Discussion* ... *289*
*6.1 Research Implications in Context* ... *289*
*6.2 Thesis Limitations* ... *302*
*6.3 Future Directions* ... *303*
*6.4 Personal Reflections* ... *308*
*6.5 Conclusions* ... *309*

**REFERENCES ... 312**

APPENDIX A – STUDY TWO QUESTIONS ... 354
APPENDIX B – RUCKAS-YOUTH SURVEY ... 355
APPENDIX C – DCSM WRITTEN EVIDENCE ... 360
APPENDIX D – RFU CITATION ... 366
APPENDIX E - RUCKAS-YOUTH 2022 FINDINGS SUMMARY ... 367

Word Count: 78,081

## List of Figures


| Figure | Title | Page |
|---|---|---|
| 1.1 | Pitch present stakeholders at a youth rugby game at club/school. | **16** |
| 1.2 | Flow chart of key stakeholder decisions following potential head injuries within youth rugby. | **17** |
| 1.3 | Van Mechelen's 4-step injury prevention Model. | **24** |
| 2.1 | Linear and rotation forces in relation to head axis of rotation. | **40** |
| 2.2 | Prevent Biometrics accelerometry mouth guard. | **46** |
| 2.3 | Brain regions and function. | **51** |
| 2.4 | Conceptualised regional brain involvement and the potential consequences of concussion. | **53** |
| 2.5 | Immediate Memory component from the SCAT3 test. | **54** |
| 2.6 | Incidence of reported match concussions by season with mean ± 2 x standard deviation shown from RFU PRISP Report 2019/20 | **75** |
| 2.7 | Incidence of reported concussions over 11 seasons for each playing level. From RFU CRISP Report 2019/20 | **78** |
| 2.8 | Standardised Assessment of Concussion (SAC). | **101** |
| 2.9 | Natus ICS Impulse - Vestibular Testing System | **104** |
| 2.10 | King-Devick Test Cards. Demo Card and Tests Card I. | **121** |
| 2.11 | King-Devick Test Cards. Tests Card II &III. | **121** |
| 2.12 | Barriers for SRC disclosure taken from Pennock *et al.*(2020) | **147** |
| 2.13 | Participant responses to questions pertaining to attitudes and influences regarding concussion risk and management. From Martin *et al.* (2015) | **149** |
| 2.14 | World Rugby decision making framework for high tackles infographic | **169** |
| 2.15 | World Rugby Research Unit (WRRU) concussion diagnosis, management and prevention research. Raftery *et al.*(2021) | **173** |

| | | |
|---|---|---|
| 2.16 | The Health Action Process Approach (HAPA) R.Schwarzer (2012) | **178** |
| 4.1 | Common characteristics of EFA’s within youth community rugby union | **213** |
| 4.2 | Consensus statement symptoms of concussion most frequently identified by youth rugby union Emergency First Aider’s (EFA’s) | **217** |
| 4.3 | Questions most frequently asked by youth rugby union Emergency First Aider’s (EFA’s) to players suspected of sustaining concussion. | **218** |
| 4.4 | The most frequently cited treatment roles/responsibilities of youth rugby union Emergency First Aider’s (EFA’s) | **220** |
| 4.5 | Most frequently cited actions taken youth rugby union Emergency First Aider’s (EFA’s) following a player’s concussion suspected removal from play. | **221** |
| 5.1 | Mean CKI as a percentage of correct answers by cohort group. | **243** |
| 5.2 | Overall mean concussion knowledge theme scores as a percentage of correct. | **245** |
| 5.3 | Mean percentage ‘Symptom Recognition’ theme scores by cohort. | **246** |
| 5.4 | Mean percentage ‘Signs and Symptoms’ theme scores by cohort. | **247** |
| 5.5 | Mean percentage ‘True or False’ theme scores by cohort. | **248** |
| 5.6 | Mean percentage ‘Complications’ theme scores by cohort. | **249** |
| 5.7 | Percentage of correct answers to ‘How long is the recommended minimum relative rest period following concussion for both adult and youth players, before a graded return to play can start?’ by cohort. | **250** |
| 5.8 | Percentage of correct answers to ‘Who is recommended to perform a medical review/assessment of a player before a return to contact-based rugby following concussion? By cohort. | **250** |
| 5.9 | Ranked overall concussion knowledge question scores as a mean percentage of correct. | **252** |
| 5.10 | Mean percentage CAI scores by cohort. | **254** |
| 5.11 | Overall mean concussion attitude theme scores as a percentage of safest attitude. | **258** |
| 5.12 | Ranked mean percentage of attitude safety scores for the ‘Pressure to Return’ theme by primary cohort. | **259** |

| | | |
|---|---|---|
| 5.13 | Ranked mean percentage of attitude safety scores for the ‘Report Triggers’ theme by primary cohort. | **260** |
| 5.14 | Ranked mean percentage of attitude safety scores for the ‘Coach Lead RTP’ and ‘Physio Lead RTP’ theme by primary cohort. | **261** |
| 5.15 | Ranked mean percentage of attitude safety scores for the ‘RTP Time’ theme by cohort. | **262** |
| 5.16 | Ranked mean percentage of attitude safety scores for the ‘Reporting Norms’ theme by cohort. | **263** |
| 5.17 | Ranked mean percentage of attitude safety scores for the ‘Prevention Strategies’ theme by cohort. | **264** |
| 5.18 | Ranked mean percentage of attitude safety scores for the ‘Reporting Consequences’ theme by cohort. | **265** |
| 5.19 | Ranked mean percentage of attitude safety scores for the ‘Symptomatic RTP’ theme by cohort. | **266** |
| 5.20a | Ranked concussion attitude statements as a mean percentage of attitude safety (upper). | **268** |
| 5.20b | Ranked concussion attitude statements as a mean percentage of attitude safety (lower). | **269** |
| 5.21 | Concussion knowledge and attitude index scores as a percentage of correct and attitude safety. | **271** |
| 6.1 | Mum’s Guide to Concussion poster. D. Silver (2017) | **296** |

## List of Tables


| Table | Title | Page |
|---|---|---|
| 2.1 | Symptoms from the Pocket Concussion Recognition Tool SCAT5. | **49** |
| 2.2 | Glasgow Coma Scale (GCS). | **61** |
| 2.3 | Overview of concussion incidence, severity and burden across three seasons (2017-18, 2018-19 and 2019-20) from the Youth Rugby Injury Surveillance and Prevention Project (YRISP) – 2019/20. | **80** |
| 2.4 | Front-on tackle contact proficiency scoring criteria from Hendricks *et al.* (2015) | **88** |
| 2.5 | Adult and Child Maddocks Questions. | **98** |
| 2.6 | SCAT modifications from Echemendia *et al*.(2017). | **108** |
| 2.7 | HIA trigger and permanent removal criteria. | **114** |
| 2.8 | Common eye movements, anatomical pathways involved and associated assessment tools. | **116** |
| 2.9 | Examples of saccadic subtypes. | **118** |
| 2.10 | The most commonly reported perceived parental concussion responsibilities from *Clacy et al*.(2016). | **137** |
| 3.1 | Median baseline K-D time(s) at age grade levels U9 to U17/18. | **192** |
| 3.2 | All reported head injuries (match and training) by season and age group. | **193** |
| 3.3 | Incidence of on-site reported head injuries per 1000 match hours by age group. | **194** |
| 3.4 | Number of reported head injuries, discrepancy time between first test and baseline and days/tests to recovery with median and inter-quartile ranges across four seasons. | **195** |
| 4.1 | Role-specific questions regarding concussion modified from Clacy *et al*.(2016). | **211** |
| 5.1 | Participant demographics, concussion history and concussion education. | **240** |
| 5.2 | Concussion education/guideline sources by sex, school type and age group. | **241** |

## List of publications

Silver D, Brown N, Gissane C. Reported concussion incidence in youth community rugby union and parental assessment of post head injury cognitive recovery using the King- Devick test. *Journal of Neurological Sciences* 2018; 388 :40-46. Available at; https://doi.org/10.1016/j.jns.2018.02.046

Silver D & Brown N. Written Evidence. CON-0021 Concussion in Sport. UK Parliament – Digital, Culture, Media and Sport Committee. 20 April 2021. Available at; https://committees.parliament.uk/work/977/concussion-in-sport/publications/written-evidence/?page=2

**Abstract**

Concussion Assessment, Management and Education Within UK Youth Community Rugby Union

Submitted for the Degree of Doctor of Philosophy - David Silver MCSP
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Concussion is widely considered a challenging injury to diagnose, assess and manage. Concussion definitions lack practicality, pitch-side assessments remain inconsistent, and key stakeholder knowledge and attitudes are poorly understood. In turn, risk reduction education strategies have lacked evidence-based foundations. These challenges are magnified within community youth participation where research has been sparse. Unlike professional cohorts, the frequency of concussions within youth community rugby has yet to be fully established. Contact sports such as rugby must address these challenges to ensure participant safety and promote sporting participation. This thesis aims to address these challenges. Collectively, the findings could then shape concussion education risk reduction interventions by governing bodies.

Study One first assessed the frequency of reported head injuries in youth community rugby union. It then established the King-Devick tests utility as a tool for community sport-based medical staff and parents to chart cognitive recovery following head injury. A prospective cohort study of 489 players (U9-U18) was conducted at a community level rugby union club over four seasons. The reported head injuries following match play (12.7/1000hrs) were higher than any previously reported. Results indicated that the K-D Test was a practical tool for baseline, post injury and parentally supervised repeated testing within youth community Rugby Union.

Study Two implemented the socio-technical systems approach employed by Clacy *et al.*(1) to identify the demographic of EFA's within English community youth rugby union and examine their understanding and perceived role/responsibilities of concussion management. A short (3 to 4 minute) audio-recorded survey was conducted on 40 Emergency First Aider's (EFA's). Despite limitations in current concussion understanding, the findings suggested EFA's may be suitable actors within UK youth community Rugby Union to foster improvements in concussion management and return to play (RTP) governance.

Study Three utilised the novel Rugby Union Concussion Knowledge and Attitude Survey (RUCKAS-YOUTH) to assess the concussion knowledge and attitude of 515 UK school-based rugby participants. Developed in conjunction with the Rugby Football Union it forms the largest investigation of its kind to date. It is the first study to include a large number of female participants, document perceived completion of the RFU DBaH concussion education programme, and assess differences in state and private school attending participants concussion knowledge and attitude. The study provides a baseline from which to both direct and then evaluate future concussion risk reduction interventions. No broad association was found between participant knowledge and attitudes towards concussion safety in rugby.

# CHAPTER ONE

## 1.0 Thesis Introduction

### 1.1 Concussion in Rugby Union

England represents the largest rugby union playing nation globally, with over two million participants.(2) The Rugby Football Union (RFU) has 2000 English member schools playing rugby union regularly.(3) The risk of injury within rugby, particularly concussion described as mild traumatic brain injury (mTBI) or Sports Related Concussion (SRC), has become the focus of extensive debate both publicly and academically. In 2002 The RFU commissioned The Professional Rugby Injury Surveillance Project (PRISP). Since the 2016/17 season, this annual report has documented match related concussion risks which have stabilised following a continued rise in previous seasons.(4) In the 2019/20 season, PRISP reported a concussion incidence rate of 19.8 times per 1000 match hours.(4) Concussion is, therefore, the most common rugby match injury and carries the greatest associated severity measured in time-loss to participation.(4) High profile incidents at elite levels and catastrophic events within the community game have drawn calls for 'harmful contact' aspects to be banned.(5) As such, head injuries have become the greatest threat to the games continued development.(6)

In contrast to concussion research at adult elite levels, evidence within rugby's much larger adult community grades remains scarce. Of the limited studies published, concussion incidence rates range widely from 0.4 per 1000 (7) to 46 per 1000 match hours.(8) In an attempt to address this and shadow the data collection from elite cohorts, The RFU commissioned the Community Rugby Injury Surveillance Project (CRISP). The

2019/20 review details injury data across rugby playing levels 3 (National League 1) to regional level 9. The report describes an incidence rate of 4.1 concussions per 1000 match play hours when league data is combined. The review describes a consistent upward trend in concussion incidence figures since 2013/14.(9) Although knowingly unsubstantiated, the researchers speculate that this trend may be driven by a growing awareness of concussion in community medical staff, coaches and players through changes in guidance or public campaigns, (e.g. 'Don't Be a HEADCASE') and increased media activity. They note that changes to the game may be a factor, but unavailable data regarding match characteristics would be needed to measure their impact.(9) This latest incidence data from 2019/20 does not represent a rise on the previous season (4.4/1000hrs) however, when the differing playing levels are sub-divided, no season-to-season consistency has been reached. It should be noted that accurate data collection outside of professional cohorts is considerably harder to achieve as incidences rates are impacted heavily by medical provision standards and player self-reporting. As such, the 2017/18 CRISP report followed a concussion match incidence level of 3.5/1000hrs by stating that, 'despite the breadth of this investigation, the researchers state that the figures represent a 'minimum estimate'.(10) The CRISP project is further discussed in section 2.5.7.

Amongst youth rugby union players, the incidence and severity of head injuries has similarly not achieved academic consensus.(5) A 2015 systematic review of youth rugby union and rugby league reported concussion incidence rates ranging from 0.2 to 6.9 per 1000 match hours.(11) A similar systematic review of Irish school rugby from 2019 reported an even wider range of 4 to 20 concussions per 1000 match hours.(12) The RFU tracked English schoolboy rugby at u13, u15 and u18 level during the 2019/20 season.(13) When the three age groups were combined, concussion incidence levels ranged from 6.8 to 8.7 per 1000 match hours.(13) Despite variability in the reported incidence, trends may become apparent as continued data collection is planned. The impact of this lack of clarity is substantial given that young people are more likely to sustain concussion,(14) experience symptoms for longer,(15) and can suffer ‘second impact syndrome’ with potentially fatal consequences.(16) Young players, therefore, represent not only the majority of the rugby playing population in the UK,(17) but the most vulnerable to concussion and its consequences.

## 1.2 Youth Rugby Concussion Context

Figure 1.1 below depicts the various pitch-side stakeholders commonly present at community level youth rugby union games. These include coaches, parents, referees, Emergency First Aider’s (EFA’s) and players. Each stakeholder plays a differing role in head injury management with potential injury observation influenced by their location relative to the pitch. Figure 1.2 shows the potential stakeholder decisions surrounding head injury assessment and management. Throughout the process, from head injury identification or reporting, to return to play (RTP), key stakeholder actions shape appropriate head injury management.


Figure 1.1 Pitch present stakeholders at youth club/school rugby match


Figure 1.2 Flow chart of key stakeholder decisions following potential head injuries within youth rugby.

When a player has been removed from play after being identified as potentially concussed, further pathways open. If present, EFA's may send a player for assessment with a more medically qualified onsite therapist. The use of concussion assessment tools by these individuals within community rugby union settings is unknown. If a player has been suspected of, or diagnosed with concussion, a 14 day rest period is directed by the Rugby Football Union (RFU) followed by a graded return to play (GRTP).(18) RFU affiliated schools and clubs are made aware of RFU guidelines through coaching workshops, school and club governance documentation and RFU website resources. The current rugby union GRTP process is outlined by the RFU(18) and is based on World Rugby, the games global governing body, recommendations.(19) The responsibility of overseeing GRTP when a player represents more than one team is variable. Key stakeholder interactions and the resulting decisions, shape the health outcomes of players following head injuries. Governing body guidelines, sporting culture and stakeholders' knowledge and beliefs influence such decisions. These factors have led to a series of interlinked challenges to consistently safe head injury management in rugby union.

### 1.2.1 Concussion Definition

In 2012 the Concussion in Sport Group (CISG) defined concussion as;

> *"A complex pathophysiological process affecting the brain, induced by biomechanical forces."*(2)

Despite concerted efforts by consensus groups to develop this into a more practical definition, consensus for a concise sport specific definition has yet to be fully achieved.

(20)(21) As a result, the process of defining when a head injury is considered ‘concussion’ remains ambiguous. Unlike most sporting injuries, the inability to easily see the pathological processes involved, make specific definitions difficult. Both laboratory(22)(23) and imaging based investigations(24)(25) have revealed much about the typical pathophysiology of concussion, but these tools have yet to be transferred pitch-side.(26) As a result, sports medicine has been unable to diagnose concussion in binary terms; Concussed, and so necessitating a removal from play and a stand-down period, or non-concussed and free to return to play. This leaves ‘suspicion’ of concussion the residing clinical trigger. The judgment of ‘suspicion’ rather than clinically defined decisions,(10) falls on those responsible pitch-side. (Figure 1.1) Without a clear definition of concussion injury, recording injury incidence is highly challenging.

### 1.2.2 Pitch-side Assessment Inconsistency

Commonly parents of players are designated as EFA’s, or within the RFU framework, as Emergency First Aiders in rugby union (EFARU).(27) At youth community levels EFA’s are often tasked with making key removal from play decisions following head injury. An EFA is defined as an individual that holds a First Aid qualification to level 2 of the National Qualifications Framework and are recommended by the RFU to be present pitch-side with all youth teams.(27) Community rugby clubs are asked to identify their designated EFA’s via the RFU online registration programme (GMS). The RFU do not require evidence of EFA qualifications and whilst first aid guidance documentation is available online, there is no defined RFU EFA specific resource. Alongside coaches, EFA's represent an important figure in player welfare pitch-side at grass roots levels. Whether their knowledge of concussion and its management impacts appropriate assessment, treatment and injury incidence rates, remains unevaluated.

### 1.2.3 Assessment Tool Limitations

The concussion research community has attempted to support the judgments of medics, coaches, teachers and parents through the development of validated, quantitative tools. Such tools measure balance,(28) coordination,(29) memory recall(30) and more recently, occulo-motor function.(31) Despite positive academic appraisal, none have translated to practical use in the field by non-medically trained individuals. The King-Devick Test (K-D) has, however, emerged as one such tool that reveals sub-optimal brain function following concussion,(32) whilst being practical for use pitch-side by unskilled persons.(8) The K-D Test is a rapid visual screening tool that assesses the speed of number reading presented on three testing cards, and requires saccades (rapid eye movements), concentration, and language function to perform.(11) Following head injury, participants have demonstrated slower K-D Test scores compared to baseline, suggesting impaired cognitive ability.(33) It has been suggested that for a comprehensive evaluation of head injury the K-D Test could be employed alongside tools such as the Balance Error Scoring System (BESS) and elements of the Standardized Assessment of Concussion (SAC).(8)(14) Alternatively, it can be used as a stand-alone side-line screening tool within a basic neurological assessment for less medically trained first responders.(34)

Despite the growing evidence for K-D Test use, its application within rugby union has been limited. The current rugby union elite level Head Injury Assessment (HIA) does not formally include a visual-based testing domain, despite calls for its inclusion.(35) This prompted the RFU to conduct a trial of K-D Test use within the top two English leagues during the 2016-17 season.(36) Prior to this trial, the RFU stated that the study had the potential to impact beyond the professional game if a validated assessment could be identified that a non-medical practitioner could perform.(35) When published in 2018 the authors report that the K-D Test demonstrated lower sensitivity (59.6%) and specificity (39.2%) for the presence of clinically diagnosed concussion than the current multi-modal HIA (74.8% and 91.3%, respectively).(36) The authors highlight that their K-D figures are in discordance with meta-analysis data reporting higher sensitivity (86%) and specificity (90%) scores,(32) which they acknowledge may be due to the differing methodologies used. In conclusion, the RFU funded report suggests that the K-D Test should be used with caution as a stand-alone remove-from-play side-line screening test in professional sport, pending further research.(36)

As yet, the utility of the K-D Test beyond the professional game by non-medically trained persons remains unevaluated. In addition, although use of repeated K-D Tests to monitor cognitive recovery after injury has been theorised,(8)(37) no studies have been conducted. If cognitive recovery following head injury occurs over time, it should be reflected in K-D Test performance during its course. When flat-lining of tests scores occurs, above that of baseline performance, full recovery can be assumed when linked to wider symptom resolution. Successful longitudinal observation assists parents, coaches, teachers and healthcare providers in planning individualised return to learn and play schedules.(8) No studies have examined the daily repeating of the K-D Test following head injury in this way.

### 1.2.4 Limited Player Knowledge and Attitude Understanding

Due to the current lack of practical assessment tools, subtlety of symptoms and complex nature of the game, EFA's tasked with identifying and managing suspected concussion require considerable player engagement to minimize risks. Player attitudes, values, and social norms, have been shown to heavily influence the reporting of symptoms to pitch-side parents, coaches, EFA's and when present, medical personnel.(38)(39) As observed in adult populations,(10) young players of several sports have demonstrated the tendency to under-report head injuries.(40-42) Young sports people also show a general lack of knowledge of advised post-concussion RTP processes.(43) Within rugby union this has been cited as a cause of poor recovery protocol adherence.(44)

### 1.2.5 Non-validated Risk Reduction Strategies

Risk reduction frameworks have become a commonly used resource when attempting to develop strategies to limit injury risk in sport. Various structures have been presented and are discussed further in sections 2.8.5 and 2.8.8. One of the most prominent is the Van Mechelen principles depicted below (figure, 1.3)(3) The Van Mechelen principles state that for an injury prevention intervention to be effective, it needs to a) establish the problem, b) establish the aetiology and mechanism of the injury, c) introduce the preventative measure(s) and d) evaluate the effectiveness of prevention strategies by repeating step a).(3) When variations in injury definitions and under-reporting lead to poorly defined incidence rates, risk reduction frameworks can be compromised, the Van Mechelen principles are no exception. Accurate incidence rates form a key pillar of risk reduction frameworks(45) and without them, the measurement of risk reduction strategy impact through the observation of incidence rate change cannot occur.(46) This has led to a lack of consensus as to concussion risk reduction strategy best practice. Introduced in 2013, the RFU 'Don't be a HEADCASE' (DBaH) concussion education programme(18) forms a core element of English rugby injury risk reduction. Concerns have been raised, however, in the UK and worldwide, regarding the effectiveness and uptake of such educational initiatives.(47-50) A common criticism being the use of reductionist strategies, such as awareness campaigns, rather than attempting to understand and address the systemic influences on stakeholder decision making.(1)(50) This is a common consequence of a lack of intervention efficacy evaluation. When evaluation is implemented, the information can be used to direct programme modifications. This has not occurred for the DBaH which has undergone no formal efficacy review. The necessity for this type of review is even greater when incidence rates cannot be used to validate targeted interventions.

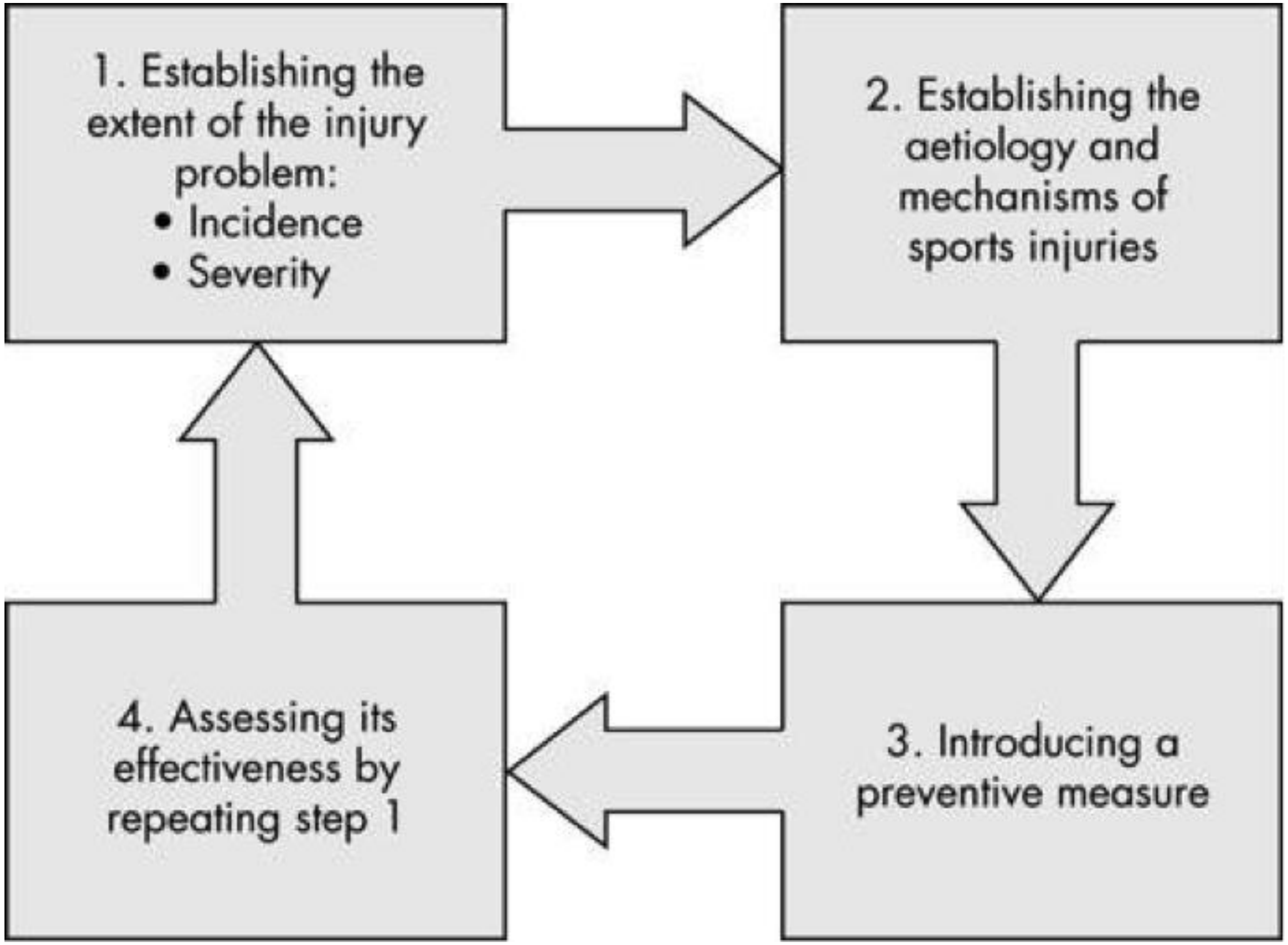


Figure 1.3 Van Mechelen's 4-step injury prevention Model

### 1.2.6 Thesis Origins

I began to consider the potential for this thesis in the autumn of 2012. I had recently completed a part-time MSc in sports and exercise rehabilitation at St. Mary's University, Twickenham whilst practicing as a Chartered Physiotherapist within sport, my dream job. One of my working roles was as Head Physiotherapist at a large community level rugby club, and upon taking the role, I quickly realised how challenging head injury assessment and management was for all involved. Every aspect seemed mired in a lack of clarity. There appeared limited evidence from which to build practical protocols and a broad spectrum of stakeholder knowledge and attitudes towards its impact on the game. Coupled with my lack of experience and expertise, I felt I could not offer the other physio's, EFA's, parent's coaches and players the guidance they dearly needed. As the key injury management lead at a club with over 800 members, the weight of responsibility felt heavy. I expressed my concerns surrounding head injuries within community rugby to my MSc colleagues and tutors. These feelings were shared by them and the medics I would meet pitch-side.

My colleagues expressed similar discomfort at the ever-rising incidence levels, lack of practical assessment tools, poor player adherence to recovery guidance and pressure they faced when making clinical decisions. These concerns were magnified in those like myself, who lacked the council of a medical team that would be present at professional levels. With the encouragement of Professor Conor Gissane, a leading figure in rugby injury research and a trusted friend and mentor, I wrote down the problems I faced. Firstly, I could not give parents any absolute clarity on the head injury risks that youth community rugby presented. Parents would ask me, 'how likely is my child to get a concussion from rugby'? At that time, I, like the wider research community, could only reply, 'we don't know'. How could a parent or player make an informed decision on rugby participation if the risks were not fully established? This felt distinctly unsatisfactory.

I could not provide the team of physios with a practical assessment tool from which to limit their reliance on their subjective clinical reasoning. This presented a weekly challenge for staff when informing players and parents that we could not really diagnose 'concussion', as its definition was so broad. 'Suspicion of concussion' became a frequent pseudo-diagnosis. The tools that had been presented were time consuming, often incompletable for players and not baseline designed. Establishing the full impact of a head injury without comparison appeared impossible without a record of normal cognitive function. Again, this left the staff feeling inadequate and parents without the clarity they sought.

This was a feeling shared by the EFA's at the club, commonly parents. If the medically trained staff struggled with concussion assessment and management, we could only imagine how challenging it felt to a minimally trained parent. Aside from this, we had no accurate understanding of their knowledge, skills or experience, and as they were always the first point of contact following player injury, this was far from ideal. No publication had previously identified this key stakeholder, let alone evaluated their understanding or impact. Without a better understanding of the EFA's, I could not ensure that suitable injury recognition, removal from play, and onward referral, was occurring.

Lastly, it quickly became apparent that at community level rugby, the players still held considerable responsibility for reporting head injuries and symptoms to coaches, EFA's and parents. This had been the case when I played junior rugby in the 80's and 90's and as my rugby playing career progressed, far more external scrutiny ensued. It appeared little had changed. My appreciation and attitudes towards concussion during my sporting and working career had changed. This meant that I had no real clarity about the knowledge and attitudes of the young players I was now responsible for. How could I, or anyone else, improve young players knowledge and attitudes if we did not know what they were? This seemed an obvious problem that needed to be addressed. With the challenges I was facing at work now defined, Professor Gissane and I began to devise a thesis that would attempt to address them. By taking a micro-view from my perspective, of a macro problem, the enormity of the task appeared more manageable and relevant. If we were successful, not only would the wider research base be enhanced, but real-world solutions for my colleagues and I could be presented. This became the underpinning framework to this thesis.

### 1.3 Summary

The risks of head injury in rugby union are considered high, however, accurate incidence rates have yet to be defined, particularly within youth cohorts. This results from a lack of practical concussion definitions driven by a paucity of objective markers. Removal from play is, therefore, based on 'suspicion' of head injury which is open to interpretation. At community levels, EFA's frequently conduct pitch-side assessments. EFA's, coaches and medical staff require the means to quantitatively assess head injuries in this environment.

Tools such as the K-D Test have been proposed to meet this need. Until a fully validated tool is in use, the understanding, attitudes and experience of EFA’s can define the outcome of a head injury assessment. There is however, a lack of awareness of EFA attributes and likely behaviours. Without suitable diagnostic tools EFA’s rely heavily on appropriate player engagement. This is influenced by young player behaviour, alongside that of their parents. Just as with EFA’s, player knowledge and attitudes towards concussion is similarly unclear. Without this understanding the efficacy of current governing body education programmes remains largely unsubstantiated.

### 1.4 Thesis Aims

This thesis aims to address the challenges of concussion assessment, management and education highlighted above in the following ways;

1. Report the frequency of reported head injuries in youth community rugby union.

2. Establish the efficacy of the King-Devick Test concussion tool for baseline and post injury assessment by community level medical staff.

3. Establish the efficacy of the King-Devick Test concussion tool for cognitive recovery monitoring by parents.

4. Establish the demographic of EFA's within English community youth rugby union

5. Examine the understanding and perceived role/responsibilities of EFA's within youth concussion management.

6. Develop and implement a survey to establish baseline concussion knowledge and attitudes of youth rugby union players which can be used as a pre risk reduction intervention baseline.

7. Present recommendations for future concussion education interventions

## 1.5 Thesis Structure

The research within this thesis was conducted over a nine-year period. The volume of concussion research has greatly increased in this time. The literature review presented in Chapter Two reflects the rapidly growing evidence base and reveals the key influencing factors and limitations to practical pitch-side concussion management and risk reduction education interventions. All references to rugby infer only to rugby union. References to rugby league are documented accordingly.

Chapter Three presents Study One, the results of a prospective cohort study designed to firstly establish the efficacy of the K-D Test for baseline and post injury assessment at youth community rugby levels, and establish reported concussion incidence rates within this cohort. In addition, Study One sought to establish the utility of the K-D Test for parentally guided repeat testing during a recovery process and describe the associated timescales. Data were collected between 2013 and 2018 and demonstrated the highest incidence rate of reported concussion at youth community rugby levels published, and remains one of the most comprehensive accounts of reported head injuries within this cohort. In addition, Study One was the first published work to describe how community level medical staff could use the K-D Test as part of a head injury assessment and how parents were actively engaged in cognitive recovery monitoring through its use as part of a RTP programme.

The conduction of Study One provided the authors with a greater appreciation of the stakeholder interactions that shape concussion assessment, treatment and RTP at community youth rugby levels. One of the most prominent findings being how key the role of Emergency First Aider (EFA) was in identifying players who, after a head injury, may be experiencing symptoms of concussion. This cohort had not been investigated previously, and so an appreciation of the knowledge, attitudes and intended role of these volunteers was imperative. Conducted during the 2017/18 season, Chapter Four's Study Two aimed to implement the socio-technical systems approach employed by Clacy *et al.*(1) within the identification of the demographics, understanding and perceived role/responsibilities of concussion management by EFA's within English community youth rugby. Study Two represents the first published account of EFA's and was welcomed by the RFU when presented in 2018.

Studies One and Two highlighted the considerable impact of stakeholder concussion knowledge and attitude on the likelihood of concussion reporting by youth players. With similar appreciation, World Rugby and the RFU have developed and implemented educational resources to increase understanding and awareness. The RFU's primary concussion education resource, 'Don't be a HEADCASE' (DBaH) has to date, not undergone a formal validation process. This is largely due to the paucity and fluctuation of reported incidents rates from which a conventional evaluation model would rely upon. To overcome these challenges, the authors, through collaboration with the RFU, developed a survey to establish youth community rugby union player concussion knowledge and attitudes.

Study Three within Chapter Five reports data obtained through The Rugby Union Concussion Knowledge and Attitude Survey (RUCKAS-YOUTH) from 2019-2022. On completion, the RUCKAS-YOUTH study represents the most comprehensive investigation of UK youth sports concussion knowledge and attitude and is the primary reference for the ongoing RFU revision of English rugby's concussion education and attitude change programme. It is anticipated to become a standardised resource as part of the concussion intervention validation processes of the RFU and wider youth sports governance communities.

With the insight and experience gained through the completion of three studies and a comprehensive literature review over nine years, Chapter Six discusses the thesis findings, implications for practice, limitations, and conclusions are then drawn as to the ongoing challenges of concussion within youth rugby. Future developments that may enhance the games safety are then presented. Where possible, the efficacy of both the reviewed literature and original studies described in this thesis, and the thesis collective impact, have been evaluated against the Van-Mechelen injury prevention model. This model is used to define the most effective means of establishing concussion problems and causes, selecting positive risk reduction interventions, appraising their efficacy, and continuously modifying them for best practice. Chapter Six describes how the thesis reflects this cyclical structure to achieve its aims.

# CHAPTER TWO

## 2.0 Literature Review

### 2.1 Literature Review Introduction

An explosion in head injury and concussion research has occurred during the last 10 years(51) prompted by heightened public attention. This literature review reflects the current key areas of knowledge growth with particular focus on youth rugby union playing populations. Non-sporting concussion research, currently focused on battlefield trauma, has been omitted. Developments in the understanding of concussion pathophysiology are discussed that form the foundational knowledge required when attempting to both define and assess concussion both subjectively and objectively. The biomechanics surrounding rugby head injuries are reviewed, essential for the evaluation of risk reduction interventions. Rugby head injury risk factors are explored that underpin the developments in risk reduction interventions. The literature review then focuses on evidence of key stakeholder concussion knowledge and attitudes before reviewing current research into concussion education both in the UK and worldwide. Each section aims to build on its predecessor to ensure the reader has a full appreciation of the factors that influence concussion assessment, management and education. The literature reviews structure from broad to focused reflects the authors near decade journey from investigation to practical intervention.

## 2.2 Pathophysiology of Mild Traumatic Brain Injury (mTBI)

The cerebral and neurological pathophysiology of mTBI/concussion is widely recognised as being highly complex and multi-factorial. Several theories regarding injury mechanisms and the resulting pathological processes have been presented. Recent studies have been made possible by advances in imaging techniques, experimental animal modelling and innovative biomarker testing procedures. An appreciation of the pathophysiology of concussion is an essential foundation that underpins knowledge of the injury's biomechanical causes, brain recovery processes, and prevention strategy development. In addition, heightened pathophysiological understanding can reveal much about the differing responses to mTBI observed between the sexes and age groups.

### 2.2.1 Diffuse Axonal Injury (DAI)

Axonal injury is widely considered the primary trigger for the resulting structural and metabolic sequale of cerebral trauma. Initial cadaveric studies in the 1940's revealed that mTBI could induce subtle yet widespread changes in white matter.(52) When linked to early pioneering experimental models, conclusions were drawn of the direct link between cerebral axonal injury and physical head trauma. The term Diffuse Axonal Injury (DAI) was coined by Adams *et al*.(53) His team built on the early works of Strict, Nevin and Oppenheimer, who in the 70's and 80's investigated the link between differing severities of trauma and resulting degree of axonal disruption.(54)(55) Following this, Adams *et al.*(56) developed a grading system of DAI based on the distribution and extent of pathology.(56) Despite hypothesising that non-fatal cerebral injury could induce DAI, all of the aforementioned pioneers remained unable to observe it without autopsy, a factor that remains the greatest challenge for cerebral injury research.

The axons inherent properties could, however, reveal its potential for acute non-fatal damage. Axons are compliant and ductile under stretch,(57) in line with the brains inherent viscoelastic properties.(58) They appear vulnerable to rapid tissue strain rendering them 'brittle'.(59) Despite full axonal severing (axotomy) appearing rare,(60) such rapid stretching has the potential to create undulations and a loss of elasticity within the axons cytoskeleton.(61) "Secondary Axotomy" where swelling induces delayed axonal rupture has also been observed.(62) As a result, axonal injury is loosely grouped within axonal swellings/varicosities and/or the presence of large terminal bulbs, features closely associated with axotomy.

Axonal swellings are widely considered the collection of transported materials and periodically appear along the axon's length, developing within hours of injury.(59) At a microscopic level, Tang-Schomer *et al*.(63) hypothesise that axonal microtubule breakage is responsible for such undulations, and the resulting impedance of the axons return to normal lengths.(63) This may interrupt axonal transportation and lead to swelling and degeneration.(63) The development of a single swelling after TBI was initially described as a 'retraction ball' and latterly as a 'axonal bulb' and is widely suggested to represent axonal disconnection.(57)

Following experimental pig studies, Chen *et al.*(64) speculates that the development of these two distinct pathologies may be influenced by differing types of forces, with uniaxial tension more closely associated with long white matter varicosities, whilst shear forces are linked with the development of axonal bulbs at grey-white matter interfaces.(64) This may have implications for sports related mTBI when correlated to the nature of mechanical impact forces. In addition, it has been established that the site of head impact influences the site and nature of injury, and therefore, axonal injury may not be as ‘diffuse’ as the title DAI suggests. To this end Smith *et al.*(59) states that the location and severity of DAI is related to the plane in which the force is applied.(59) The timescale of the axon cytoskeleton’s ability to repair, if at all, and any association with symptom resolution, remains intriguing and yet to be fully evaluated.

### 2.2.2 Neuro-metabolic Cascade

DAI appears to be only the start of what is commonly described as a ‘neuro-metabolic cascade’.(65) Normal axonal transmission requires receptor activation and the subsequent ionic changes in neuro-transmitting cell membranes.(66) Ionic changes are closely regulated by sodium, potassium, and their associated ATPase pumps.(67) If cell membrane disruption occurs with DAI, altered membrane potentials can result in a loss of ionic equilibrium.(68) The following substances have been implicated in this process.

### 2.2.3 Potassium & Glucose

The binding of excitatory neurotransmitters abruptly released after injury such as glutamate to N-Methyl-D-Aspartate (NMDA), has been shown to spark neuronal depolarisation.(69) This results in a mass cellular release of potassium and intake of calcium. In reaction, the sodium-potassium pumps appear to fire greatly to deal with the rising potassium levels.(70) Glucose metabolism then increases to meet the associated Adenosine tri-phosphate (ATP) need of the pumps.(68) Giza *et al.*(65) describe this process as ‘hypermetabolism’.(65) Compounding the drive for increased energy to manage raised potassium is the reduction in cerebral blood flow commonly observed acutely after mTBI.(65)

### 2.2.4 Cerebral Blood Flow

Following extensive animal studies,(71)(72) recent investigations into human cerebral blood flow (CBF) following mTBI have been undertaken. It has been observed in both adult(23) and paediatric populations(73) that reductions in CBF assessed via MRI(74) and Doppler ultrasonography(75) are not only correlated with mTBI, but also a subsequent reduction in cognitive function.(23)(73) It has, therefore, been hypothesised that the measurement of CBF may be a useful tool in predicting recovery following mTBI.(23)(73)(75) Impaired CBF and its cognitive effects remains an exciting area for research and is discussed further in sections 2.4.6 and 2.6.2.

### 2.2.5 Calcium

The processes surrounding the observed increases in cellular calcium intake are less well established.(60) It is hypothesised by Kilinc *et al.*(76) that breaches in the axolemma following DAI may allow calcium to seep into cells.(76) Activation of trans-membrane, voltage-gated channels, stimulated by sodium entry, may also play a distinct role.(60) It should be noted that some studies have found that intra-cellular calcium stores are released in addition to extra-cellular uptake following axonal injury.(77)(78)

It has been widely established that the rapid increase in intracellular calcium activates the release of the protease Calpain, linked with catastrophic damage to axonal cytoskeletons and ion channels.(57)(76)(78)(80) In addition, over production of protein kinases,(81) phospholipases,(82) nitric oxide synthase and endonucleases, have all been observed.(65) It has been suggested that over activation of these substances may lead to free radical over-production,(83) cytoskeletal reorganisation and activation of apoptotic genetic signals.(65)

Free radicals, molecules attempting to gain electrons from surrounding substances, are suggested to be a natural product of metabolic cellular activity. Raised levels can, however, lead to cell membrane, protein and DNA damage.(68) Confirmation of these substances role within human mTBI remains to be established. Increases in these substances may be a plausible cause for secondary axotomy. Giza & Hovda(65) stress that increases in intracellular calcium and its consequences does not inevitably lead to cell death.(65) The ongoing study of calcium's role following mTBI, its return to pre-injury levels, correlations to recovery time, and lasting cerebral pathology, remain key research topics.

### 2.2.6 Mitochondrial Dysfunction

Mitochondrial dysfunction has also been presented as a potential cause of secondary axotomy through its close link with calcium management. Osteen *et al.*(84) observed overloading of mitochondria with calcium acutely after TBI that resulted in oxidative stress.(84) A link between a reduction in mitochondrial performance and cognitive deficits has been presented.(85)(86) Several research groups are investigating ways to limit secondary axotomy linked with dysfunctional mitochondria.(79)(87) In addition to the mitochondrial dysfunction and axonal disruption discussed above, neuro-inflammation and microglia activation have been implicated in ongoing cellular damage following TBI.

### 2.2.7 Neuro-inflammation/Microglial activation

Many studies have reported the presence of an acute central nervous system inflammatory response following traumatic brain injury.(88) Within the more frequent milder forms, a growing body of evidence reveals similar processes. Inflammatory cells respond quickly to injury via what has been described as a sterile immune response (SIR).(89) Astrocyte, microglia, monocytes, macrophages, neutrophils, and T-Cells, all initially designed to promote tissue homeostasis following DAI, have been linked to this process.(90) Microglia, a highly dynamic CNS inhabitant linked with synaptic plasticity, has been reported a first responder to an inflammatory process,(91) occurring within a few minutes of injury.(90) Microglia have been implicated in the phagocytosis of debris and the down-regulation of cellular metabolism following DAI. It appears Microglia mediates the release of Reactive Oxygen Species (ROS) known to induce cell death and inflammation, a potentially beneficial, but also counter-productive occurrence.(90) Although Microglia are perceived to have a primarily protective impact within the cortex, debate persists as to the efficacy of the other substances commonly seen. This led to the clinical trial of several potentially therapeutic interventions designed to effect and control their actions. Despite limited wider success, recent research has focused on the role of ROS and their potentially negative impact on neuronal cells. The development of therapeutic antioxidants to manage ROS and other associated maladaptive substances may prove to be beneficial in the treatment of mTBI. In addition, accurate diagnostic tools to measure these biomarker levels may provide breakthroughs. Whether milder TBI patients could also benefit from such assessment and interventions remains to be seen.

## 2.3 Biomechanics

Parallel to increased patho-physiological understanding of concussion, evaluation of the biomechanical factors that precede head injury is developing. By understanding the nature of what leads to a concussive event, sport's governing bodies may be able to make informed decisions on laws and regulations that may contribute to protecting participants. As such, the following section focuses on the forces and kinematics associated with concussion.

### 2.3.1 Physical Forces

Investigation of the forces involved with concussive injury began in the 1960's. Research groups investigated the degree of acceleration required to produce concussion, culminating in developing the Wayne State Tolerance Curve.(92) This theoretical model, primarily devised to investigate car crash tolerances, was used to correlate the risk of injury with the degree of linear acceleration over time.(93) Although pioneering, this model did not account for angular movements of the head that have since been linked with higher degrees of injury.(93) Ommaya and Gennarelli (94) who's research groups remain leading figures in concussive biomechanics, furthered understanding during the 1970's by assessing the role of linear versus rotational acceleration for brain injury. Their research predicted that shear forces, caused more readily by rotational inducing impacts, were the primary cause of concussive injury.(Figure 2.1)(53)(94)(95) Ommaya and Gennarelli(94) noted that shearing around the midbrain, upper brain stem and cerebellum, areas responsible for alertness and responsiveness, appeared more frequent with rotational forces than linear forces. Subsequently, it has been established that a higher loss of consciousness (LoC) is associated with rotation inducing impacts,(94) with several studies demonstrating that higher rotational velocities lead to lower concussive thresholds than linear force counterparts.(96)(97) Such investigations have classically utilised small mammal experimentation, cadaveric studies, or more recently computer modelling. As such, the lack of 'real world' correlation has remained a constant limitation.(98) In addition, the research focus has been directed towards major car crash trauma and not the milder, more frequent spectrum of injury. Recent attempts to address these issues have drawn researchers towards kinematic studies during sports participation.

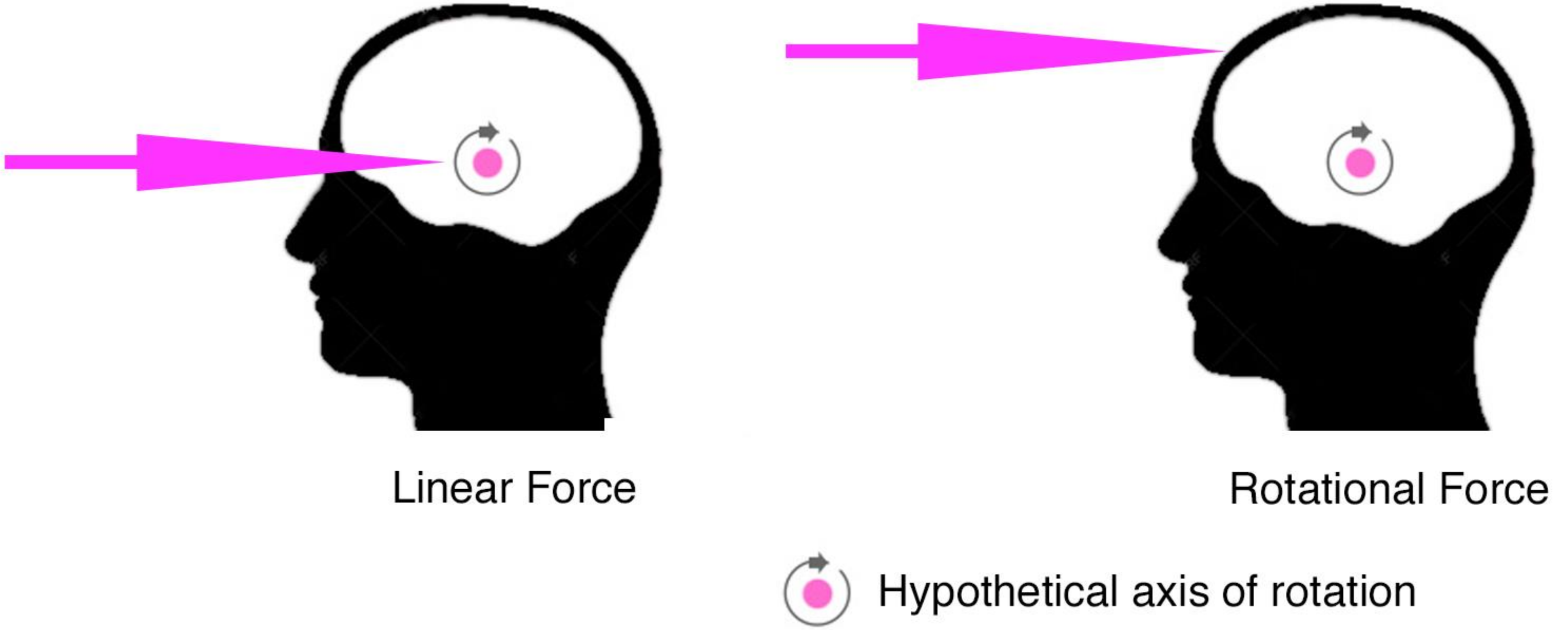


Figure 2.1 Linear and rotation force in relation to head axis of rotation

### 2.3.2 Kinematics

The most extensive mTBI sport specific research has been conducted within American Football. In response to the sharp rise in concussion awareness following National Football League (NFL) brain injury legal proceedings, the NFL commissioned an investigation of sports related concussions. Several studies emerged from laboratory reconstructions of video recorded concussions(99) to Finite Element Modelling (FE).(100) The key goal was to establish the specific nature of the forces that could lead to concussions on the field.

The most extensive studies have used in-helmet devices. Duma *et al.*(101) pioneered the use of the Head Impact Telemetry (HIT) systems within American Football helmets and reported force magnitudes of 25*g* - 32*g* during college practice and games.(101) To contextualise, Bussone and Duma commonly report <10*g* events as part of normal activities of daily living.(102) Similar larger studies within American Football reported lower values of 20*g* – 23*g*.(103) By combining the data sets taken during practice and games with exposure rates, incident levels could then be established. Dramatically Mihalik *et al.*(104) found that College American Football players experience approximately 950 sub concussive (non-injury) episodes per season,(104) a similar figure (967) to that established separately by Schnabel *et al.*(105).

By aligning the accelerometry data of participants conventionally diagnosed as being concussed, force thresholds began to be speculated.(98) The initial studies conducted by the NFL Research Group used sophisticated laboratory based reconstructions of player impacts captured on video. By reconstructing 31 collisions and applying mathematical force calculations, Pellman *et al*.(98) suggested that mTBI impacts were likely to occur between 70*g*-75*g*.(99) This seemed to contradict previous investigation that reported only a tiny fraction of impacts (7/1858) above 80*g* led to mTBI diagnoses.(106) Despite the strides made by these pioneering studies, subject numbers remained low and methodologies frequently questioned. The most common criticism involved the lack of human anatomical data inclusion that may help explain why some individuals may be more susceptible at lower thresholds than others. By adding cadaveric intracranial pressure data to computational modelling, Zhang *et al.*(107) determined that responses to injury based on brain tissue could be calculated. By replicating 24 head-to-head impacts the researchers reported head accelerations of 66*g*, 82*g* and 106*g* that were associated with 25%, 50% and 80% probabilities of mTBI.(107) Additional research incorporating rotational accelerations,(108) found similarly broad findings, all in excess of previously considered thresholds. Greater doubt was shed on the notion that a rigid threshold could viably be set. When studying 22 College American Football players, all exposed to at least one over 90*g* impact, Guskiewicz *et al.*(106) found that none of the players demonstrated reduced balance or cognition between 16-24hr after. Again, this seems to imply that high impacts do not necessarily lead to concussion and the previously regarded thresholds of around 75*g* may be far from accurate.(106) As in-helmet accelerometer use has grown, comparisons of force data with conventional concussion assessment has narrowed speculated concussive force thresholds. Levels for impacts reported as greater than 95*g* and 5500 rad/$s^2$ are beginning to form consensus,(108) but many variables remain unaccounted for.

Since the development of in-helmet HIT systems in the early part of the century, sensor technology has grown alongside understanding. 6-axis systems are currently under review aimed at increasing the relative accuracy of cerebral displacement.(109) In parallel to the drive to create greater force sensitivity through hard and software advances, means to make accelerometry more discrete, and therefore, practical for non-helmet wearing sports, has been developed. The advent of gum shield accelerometry pioneered by Camarillo *et al.*(110) within American Football,(110) further negates the need for helmet or head attached devices. Its discrete nature would make it seem ideal for non-helmet contact sports such as rugby. To this end King *et al*.(108) began its use within rugby union by following a squad of 38 amateur players over a season.(108) A total of 20,687 impacts over 10*g* were recorded using the X2BioSystems Inc. instrumented mouth guard. Incorporating a tri-axial accelerometer and angular rate gyroscope, the mouth guards reported impacts ranging from 10*g* to 164.9*g*. The study reported impacts over 10*g* to the head per player, per match, over the duration of the season, far higher than previously reported in College American Football.(105)(111) Mean linear accelerations of 22*g* were recorded which fell within similar ranges to College and Youth American Football. Using the hypothesised 95*g* and 5500 rad/$s^2$ concussion threshold derived from previous studies, King *et al.*(108) reported 181 impacts over 95*g* and 4452 impacts over 5500 rad/$s^2$.(108) Despite difficulties in comparisons with helmeted research, it was suggested that rugby union players are exposed to impacts considered well above concussive injury levels and frequently experience sub-concussive ‘mild’ events.(108)

The pioneering nature of this study and burgeoning technology used, made comparisons difficult and its methodology debatable. King *et al.*(108) noted gum shield and accelerometer concerns that may explain why a large percentage of errors were reported for the reliability of the impact variables. They speculate that this may be why no strong relationships were found between impact variables and concussions.(108) Similar technology has also been incorporated into wearable patches in an attempt to negate some of the operational issues King *et al.*(108) found. 6-axis impact patch devices, developed by the same manufacturer as the gum shields discussed above, have been in use with English Premiership and Australian first grade rugby union clubs.

The most recent, large scale study to utilise mouth guard accelerometry has built on the technology advances and experience gained over the last decade detailed above. The University of Otago, New Zealand, in collaboration with US based technology company Prevent Biometrics have begun a research project that aims to evaluate the head impact forces experienced during rugby by 700 adults, under 18, under 15 and under 13 male and female players.(112) The project will incorporate the Prevent Biometrics impact monitoring mouthguard. (figure. 2.2) The project is backed by World Rugby who state that;

*"The study will help World Rugby further understand the nature of head impacts at the respective community levels, to measure what is happening to the brain during any impact in match and training environments versus normal, non-contact activity. This will assist with making recommendations to further inform rugby's injury-prevention strategies as World Rugby continues its research-led drive to protect players at all levels of the game."*(112)

The study commenced in April 2021 and if successful, may define head impact data collection methodologies in rugby and the wider contact sport world.


Figure 2.2 Prevent Biometrics accelerometry mouth guard.

Despite considerable developments within in-game and practice force detection, several key limitations have been cited and areas for future study presented. As with many epidemiological studies, the primary challenge remains the degree of human variables to be accounted for.

Aside from the informative nature of peak accelerations described in the studies above, developing injury risk and exposure profiles by collating data across studies has proved challenging. This appears a result of the non-linear relationship between peak acceleration and injury tolerance.(113)(108) This led Urban *et al.*(114) to state that its isolated use may leave a misleading picture of exposure.(114) To address this, Urban and colleagues developed a cumulative computed risk score know as Risk Weighted Exposure (RWE). Through the investigation of 40 high school American Football players via helmet accelerometry, cumulative exposure rates were predicted through conventional accelerometry in combination with adjustments based on impact tolerance. This was used to establish an impact RWE for each player.(114) The development of this tool has been speculated to provide a better understand of the cumulative effects of repetitive head impacts, injury mechanisms, and head impact exposure.(114) Within rugby, King *et al.* (108) states that incorporating RWE in future studies using accelerometry may help investigators identify players with potential cumulative exposures to concussion.

The understanding of the biomechanical factors that define concussive head injury has grown rapidly in the last decade. Advances in new technology and exposure measures should continue to refine our knowledge. Linking these factors to clinical sequale remains the overarching goal.

### 2.4 Symptoms

The symptoms list depicted below is taken from the Concussion Recognition Tool (115) part of the Sport Concussion Assessment Tool (SCAT5).(116)(Table 2.1) The amount highlights the wide and varied symptoms that frequently accompany concussion. Despite its length, this list is far from exhaustive and a growing body of research has found deficits in a host of other cognitive, behavioural and motor skill areas.(117)(118) Concussion symptoms typically resolve in 80–90 % of all sport participants by seven to ten days post-injury.(119) The breadth of post-concussion symptoms also correlates with the length they are experienced for.(120) Developments in innovative imaging, biomarker and screening tools, discussed in depth below, have enhanced our understanding of the neurophysiological links between symptoms and pathology. Despite this, much remains unknown regarding the link between observable and reported symptoms and brain recovery post injury. Enhancing this understanding is a key focus of this thesis and for the wider SRC research community.

Table 2.1 Symptoms from the Pocket Concussion Recognition Tool SCAT5.(115)

STEP 3: SYMPTOMS

| | | | |
|---|---|---|---|
| Headache | Blurred vision | More emotional | Difficulty concentrating |
| “Pressure in the head” | Sensitivity to light | More irritable | Difficulty remembering |
| Balance problems | Sensitivity to noise | Sadness | Feeling slowed down |
| Nausea or vomiting | Fatigue or low energy | Nervous or anxious | Feeling like “In a Fog” |
| Dizziness | “Don’t feel right” | Neck pain | Drowsiness |

### 2.4.1 Memory Disruption

Temporal lobe structures shown below, (Figure 2.3) especially the hippocampal formation and associated cortical and subcortical structures, are commonly associated with episodic memory loss following concussion.(121) Umile *et al.*(122) report that up to 75% of patients demonstrate medial temporal lobe abnormalities through visual and verbal memory testing in combination with Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT) imaging following concussion.(122) As a result Toledo *et al.*(123) echo consensus that assessment of memory disruption should always be considered as part of an initial clinical assessment.(123) Memory impairment was initially incorporated in sports concussion assessment in the form of the Maddocks Questions, developed in the early nineties.(30) Through a 7-year study of professional Australian Rules Football (AFL), Maddocks *et al.*(30) linked disturbances in player orientation through the incorrect answering of basic short-term memory questions to concussive head injury.(30) This format was built on the premise that information recently acquired is more sensitive to concussive impacts. Maddocks *et al.*(30) cite the work of neurologists Gronwall and Wrightson(124) and Yarnell and Lynch(125) to this end.

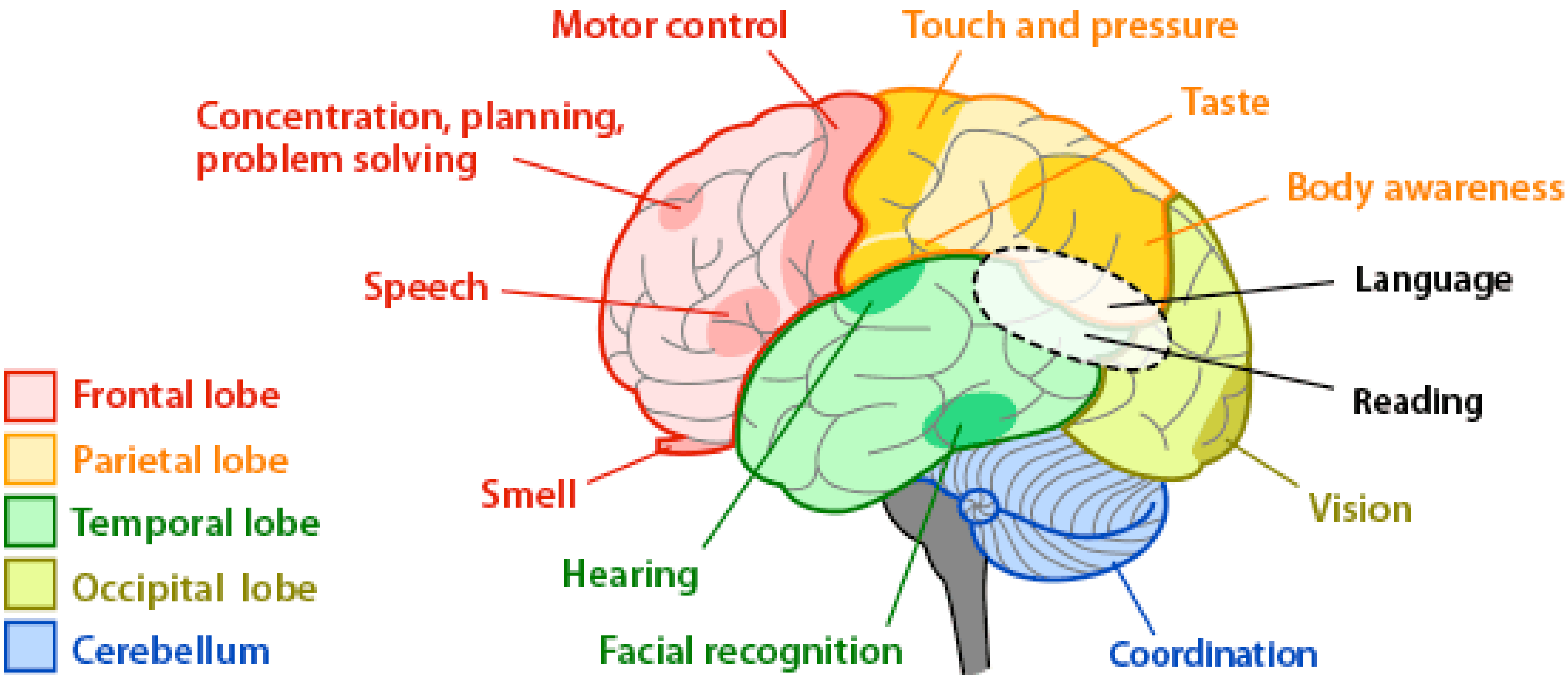


Figure 2.3 Brain regions and function. (126)

Intriguingly Yarnell & Lynch(127) also documented the phenomena of 'Post Traumatic Amnesia'.(127) Through studying American Footballer's after a head impact induced loss of consciousness (LoC), Yarnell and Lynch(127) found that accurate information about the preceding passages of play was reported immediately, but not 3-20 minutes later. They hypothesised that this was due to impaired ability to 'form' longer-term memories. The use of the Maddocks questions in concussion assessment is discussed in Section 6.3.

#### 2.4.2 Neuro-Cognitive Function

Due to its size and location, the frontal lobe is commonly associated with head injury.(123) Heavily involved with the cortical systems of neuro-cognitive function, concentration, problem solving and verbal fluency depicted below, (Figure 2.4) frontal lobe impairments are almost always present following acute concussive head injury.(123) Deficits in Working Memory (WM), likened to the 'online' storage of information necessary for performing cognitive operations by McAllister *et al*.,(128) is one of the most recognised and assessed neuro-cognitive symptoms. WM was linked through functional MRI (fMRI) to the frontal and parietal areas shortly after the technologies birth.(129) fMRI has repeatedly been used to link neuro-cognitive function deficits to mTBI since.(130) WM deficits have been shown to manifest through impaired repeating of words(131) as used within many cognitive tests including the SCAT series shown overleaf. (Figure 2.5)

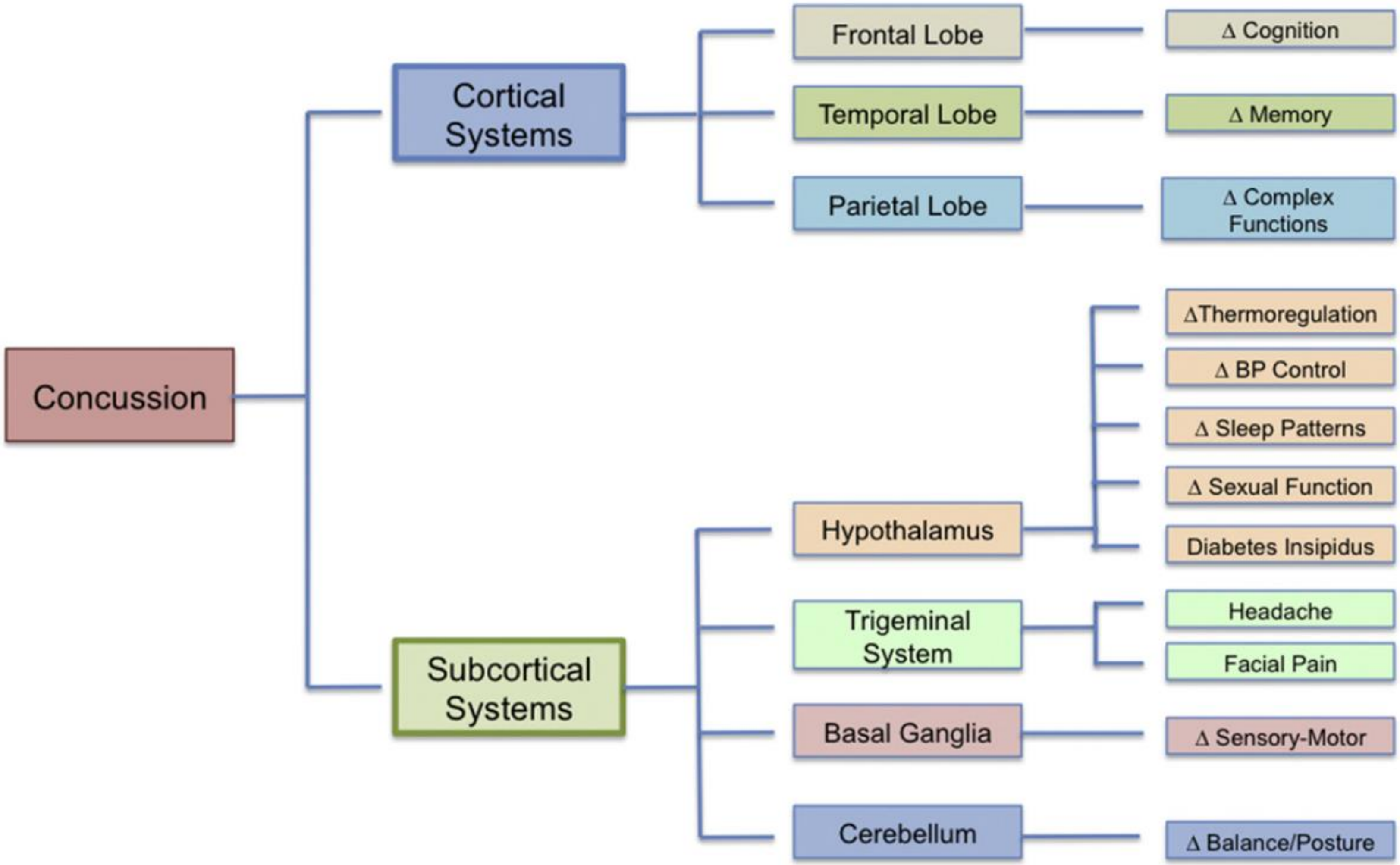


Figure 2.4 Conceptualised regional brain involvement and the potential consequences of concussion.(123)

## Immediate memory

| List | Trial 1 | Trial 2 | Trial 3 | Alternative word list | | |
|---|---|---|---|---|---|---|
| elbow | 0 1 | 0 1 | 0 1 | candle | baby | finger |
| apple | 0 1 | 0 1 | 0 1 | paper | monkey | penny |
| carpet | 0 1 | 0 1 | 0 1 | sugar | perfume | blanket |
| saddle | 0 1 | 0 1 | 0 1 | sandwich | sunset | lemon |
| bubble | 0 1 | 0 1 | 0 1 | wagon | iron | insect |
| **Total** | | | | | | |

**Immediate memory score total** of 15

Figure 2.5 Immediate Memory component from the SCAT3 test.(132)

### 2.4.3 Spatio-Temporal Impairments

Spatio-temporal impairments have been observed within rats following induced mTBI. By studying the neuronal activity of rats conducting a swim maze test, Eakin and Miller(133) found both reductions in spatio-temporal performance physically and cortically following induced concussion. Concussed rats experienced differing neuronal activity without any observable neuron loss. This led the rats to struggle to negotiate previously experienced maze pathways.

Within sport, the impact of concussion-induced reductions in the spatio-temporal capabilities of athletes has begun to be assessed. Using both a visual working memory task and an auditory task, Tapper *et al*.(134) used two working memory tests to assess the multi-task capabilities of varsity hockey players with a history of concussion.(134) Under the premise that dynamic sports athletes divide their attention between visual and auditory stimuli, thus holding information in memory to guide actions, they found that athletes with a history of concussion have more difficulty processing multiple sensory inputs simultaneously. In addition, they found that auditory functions were most impacted within previously concussed groups.(134) Despite not assessing in-game, real world sporting deficits, these findings may support a link between spatio-temporal impairments and higher risks of injury due to reduced awareness/ability post-concussion.(134)

### 2.4.4 Mathematical difficulties

Mathematical difficulties have been associated with working memory impairments.(135) Van Beek *et al*.(135) set out to characterise such impairments by comparing behavioural and neuro-imaging results of children with sub-acute mTBI to normally-developing controls.(135) Through the use of Diffusion Tensor Imaging (DTI), discussed in more detail below, Van Beek *et al.*(135) found that post mTBI children performed significantly more poorly than controls when asked to complete simple tasks of rapid object numerating and procedural problem solving. The performance differences noted were hypothesised to be a result of impaired visuo-spatial working memory, suggesting that the observed mathematical difficulties may be a consequence of impairments in visuo-spatial abilities.(135)

### 2.4.5 Cognitive-Linguistic Deficits

Despite not receiving the depth of academic attention of more prominent mTBI consequences, cognitive-linguistic deficits and communication impairments are often cited to follow head injury. Linked to temporal and parietal areas,(123) Barwood and Murdoch(136) demonstrated impairments to recall, organization, making inferences, naming and perception/discrimination when comparing 16 post-concussion patients with 16 matched controls. Their results suggest that both high-level language and isolated general language performance can be significantly reduced in mTBI patients.(136)

### 2.4.6 Headache

Headache is consistently documented as the most commonly reported post-concussive symptom.(137-139) Despite limited evidence, it has even been reported that the milder the TBI, the more common headaches are.(137)(140) Prevalence of post concussive headaches range from 22.5% to 71% of all patients within current literature.(138)(139) Youth populations demonstrate similarly broad prevalence and have been documented as occurring in 86% of youth and college athletes following mTBI.(141) Linked with the trigeminal system,(123) no clear correlation between a single specific pathological process and headache has been presented to date despite several hypothesis being presented. These have been commonly categorised into Vascular, Structural/Axonal or Cervico-genic.

DAI including tearing of extra-cranial dural afferents(142) and resulting ionic imbalances have been commonly implicated in post-traumatic headaches.(143) Giza and Hovda(65) specifically link ionic imbalances in intracellular calcium and extracellular potassium, in addition to the release of excitatory amino acids, with mTBI. Evidence for a link between biochemical imbalances and headaches can be found through the successful use of targeted migraine medication with both post-traumatic injury and insidious onset symptoms. Erickson(144) found positive effects for both a cohort of post-blast concussive trauma patients and those of insidious onset, following administration of Topiramate, an anticonvulsive drug. Erickson cites the activation of the trigemino-vascular system and release of neuropeptides from trigeminal nerve terminals as the reason for its efficacy.(144) Not only does this link biochemical changes but also vascular compromise to post-traumatic headache.

Damage to the trigemino-vascular system, including structures such as the circle of willis, extra-cranial, basilar, dura and pia matter blood vessels, that receiving innervation from the trigeminal ganglion, have been implicated in post concussive headaches as discussed above.(145) Such vascular damage is considered highly common after traumatic brain injury(146) and therefore, should not be discounted within milder forms. Whether its impact is direct or in combination with biochemical alterations remains unknown. As with several other post concussive symptoms, global alterations in cerebral blood flow without direct trauma have also been linked to headaches.(147) Sometimes persisting as long as 6–18 months post original insult, altered blood flow has been seen to show regional and hemispheric asymmetries(148) and could be considered for targeted therapeutic intervention.(147) Whether alterations in cerebral blood flow play a primary role in the pathogenesis of post-traumatic headache is yet to be fully established. The potential interventions noted above, however, may further reveal its degree of symptom causality.

A common cause of chronic insidious onset headaches, the upper cervical spine that affects spinal nerves C1–C3, has been linked with similar symptoms post mTBI.(149) Changes in muscular patterning, joint range and inflammation, and central and peripheral nervous tissue sensitisation have all been implicated through association to these areas.(150) As the cervical spine is commonly involved in concussive injury, distinguishing its involvement in any post-traumatic symptom is challenging. It has been speculated that targeted therapy to the cervical spine may be a suitable treatment for post-concussive headache suffering patients, as it is with insidious onset cases.(141) It should be noted that the efficacy of any such interventions is yet to be established.

Linking both potential cervico-genic and vascular causes, Linnman *et al*.(151) states that whiplash patients report similar symptoms to those observed in mTBI including headache, cognitive disturbances such as impaired memory, poor concentration, mental fatigue, sleep impairment, sensory sensitivity, visual disturbances and vertigo, and links these symptoms to perfusion abnormalities. Heyer *et al.*(117) also noted similarities between post-concussion headache and migraine symptoms in youth cohorts and suggests that in some instances, post traumatic headache may actually be more migraine in nature.(117)

The breadth of potential causes listed above alludes to the multifactorial and patient specific nature of post concussive headaches, making them hard to define.(123) This also makes treating this symptom challenging. Continued evaluation of targeted post concussive headaches will shed further light on the complexities of their aetiology.

### 2.4.7 Balance Disturbance and Gait Disruption

Balance, gait disturbance, postural control and dizziness are all commonly reported symptoms following mTBI.(152-154) Such symptoms have been linked to Cerebellar dysfunction, the cortical area highly involved with motor co-ordination. (see Figure 2.3) The cerebellum's propensity for injury has been associated to the close proximity of incongruous bony structures that project from the base of the skull.(155) This may lead to a higher likelihood of shearing than at higher cortical areas. Due to the observable nature of postural control and balance disturbance, assessment of these factors as a predictor for mTBI severity has, and continues to grow. Balance assessment is discussed in detail in section 6.3

### 2.4.8 Loss of Consciousness

Despite Loss of Consciousness (LoC) being the most obvious and perhaps concerning symptom of concussion, it has been observed in only 8-9% of all mTBI diagnoses.(156)(157) As 'consciousness' by definition is more than a binary state, the Glasgow Coma Scale was developed to assess the spectrum of conscious levels in those with impairments.(158)(Table 2.2 below) In response to the skill and time required to conduct the full GCS,(159) simplified measures more suitable for acute trauma environments have been developed. The most widely used being the AVPU scale (A-Alert, V-Responds to voice, P – Responds to pain, U – Unresponsive). On the AVPU scale 'unconsciousness' would correspond to U (Unresponsive). LoC as a result of the milder forms of head trauma associated with sport tends to be brief in nature. Unconsciousness lasting longer than 30 minutes is thought to indicate a more serious form of brain injury than concussion.(160) The full pathophysiology of LoC resulting from traumatic injury remains largely unknown. Kelly *et al*.,(158) however, speculates that the sudden electric discharge or depolarisation of nerve cells throughout the brain following mTBI can be enough to trigger LoC.

Table 2.2 Glasgow Coma Scale (GCS) (161)

| Eye opening | | Verbal Response | | Motor Response | |
|---|---|---|---|---|---|
| | | | | Obeys commands | 6 |
| | | Orientated | 5 | Localising Pain | 5 |
| Spontaneous | 4 | Confused Speech | 4 | Flexion Withdrawal | 4 |
| To Command | 3 | Inappropriate Words | 3 | Abnormal Flexion | 3 |
| To Pain | 2 | Incomprehensible Speech | 2 | Extension Response | 2 |
| None | 1 | None | 1 | None | 1 |

### 2.4.9 Occulo-motor Disturbance

Deficiencies in vision and occulo-motor function have begun to be considered a highly significant and measurable symptom of concussion. Ventura *et al*.(162) state that this is a result of approximately half of the brains neuronal connections being associated with vision. It would, therefore, seem likely that any cortical disruption will have an impact on visual function.(162) As a result, tools that assess occulo-motor function have started to gain traction in the mTBI assessment field. These range from the K-D Test, discussed in depth in section 6.4, to more sophisticated methods such as pupillometry and portable eye movement trackers.(162) The growing weight of research behind such tools makes them highly likely to remain at the vanguard of pitch-side management strategies and could influence RTP guidelines.

### 2.4.10 Other Symptoms

In addition to the symptoms described above, several other sequale have been noted in the literature. Alterations in sleep and circadian rhythms following mTBI have been documented in between 30% and 70% cases.(163) This may be particularly the case in young populations. Milroy *et al.*(164) note greater increases in sleep disturbances documented by parents of children following mTBI, 6 months after injury, over orthopaedic controls.(164) Depression, anxiety,(118) appetite changes,(123) thermoregulation(165) and sexual dysfunction,(166) have also been widely observed and investigated. A key focus for future research is the linking of the recordable symptoms discussed above to observable pathology. Advances in imaging techniques have begun to make this achievable and are discussed in detail below. To then link pathology, symptoms, and mechanism of injury together, would enable a far more rounded understanding of sporting mTBI. Mychasiuk *et al.*(167) pointed towards how symptoms can be linked to observable pathology. Through the study of rodents exposed to differing concussive forces, they found that after experiencing similar early motor control and behavioural symptoms, rodents exposed to lateral impact displayed deficits on tasks related to emotional functioning, whereas animals sustaining vertical forces showed impairment in cognitive measures as time passes.(167) The researchers conclude that they have demonstrated that injuries in different cortical networks and connections result in altered functional deficits.(167)

## 2.5 Risk Factors

Understanding the nature of the risk factors associated with sporting head injuries is an essential component of risk reduction strategies. The key risk factors of sex differences, age, genetics, learning difficulties, previous concussion, neck strength and sports specific risks are discussed below. Rugby specific risks including headgear and contact nature are then highlighted in detail. This thesis aims to enhance understanding of the risk factors associated with SRC with particular focus on sex and age within rugby. A greater appreciation of these risk factors could assist in the development of enhanced assessment and management strategies.

### 2.5.1 Sex Differences

Sex differences in concussion incidence and outcomes have been researched.(102)(168)(169) Following an extensive literature review, Dick *et al.*(170)

surmise that female athletes may be at greater risk of concussion than male counterparts.(170) Outcomes following concussion also appear worse in women than men, as does mortality and severity following moderate to severe head trauma.(169) Within sports concussion Covassin *et al.*(171) found that female athletes appear more vulnerable than male counterparts through the assessment of collegiate athletes. Intriguingly, however, Dick *et al.*(170) noted that the self-reporting nature of concussion data used within many studies could bring into question whether the conclusions drawn are due to true epidemiological factors, or women being more honest than men. In 2009 Dick *et al*.(170) observed that little physiological reason had been presented in the literature for the differences in prevalence and outcomes witnessed.(170) More recent physiological theory as to why male and female brains may differ in response to head injury has focused on two areas; differences in white matter volume and neck strength. The first investigation to review structural brain differences by sex following concussion was conducted in 2014 by Fakhran *et al*.(492) The study which incorporated Diffusion Magnetic Resonance Imaging (dMRI)(discussed in section 2.6.2) scanned 47 males and 22 females following confirmed concussion. Male concussed individuals demonstrated greater Fractional Anisotropy (FA), a sign of neural integrity, in the uncinate fasciculus compared to concussed females or controls.(4)

In 2018 Sollmann *et al*.(493) progressed this burgeoning field through an investigation of sex differences in white matter alterations following repetitive sub-concussive head impacts in collegiate ice hockey players. The study of 14 male and 11 female athletes who underwent dMRI demonstrated differences in male and female white matter diffusivity during the course of a season. Decreases in FA and increases in mean, axial and radial diffusivity, varying signs of white matter disruption, were observed in females. Males showed no significant changes in these measures.(5) Alongside neck strength differences, the authors suggest that differences may be due to varying hormonal levels that may either promote or diminish post brain injury recovery mechanisms. Continued research of the impact of hormone effects on concussed brains should further define their role. Alongside brain differences, neck strength research has been a commonly cited reason for the differing concussion risks between the sexes. See section 2.5.6 for detail regarding neck strength and sex differences.

Despite ongoing investigation, the lack of clarity as to sex difference responses to mTBI has led the Consensus In Sport Group (CISG) to refrain from identifying sex differences as a 'Modifying Factor' in injury management, despite noting that sex differences may be a risk factor and influence severity.(132) The consensus statement position may have to be revised as greater evidence is presented.

**2.5.2 Age**

It is widely regarded that the young brain is more vulnerable to concussive trauma than that of an adult.(123) Longer recovery times have also been observed and become accepted in the management of young populations.(14)(172)(173) Catastrophic injury as a result of head trauma is also more frequent in young people.(14) Guskiewicz *et al.* (156) identified the degree of myelination, blood volume, blood–brain barrier, cerebral metabolic rate of glucose, brain water content, blood flow, number of synapses and geometry and elasticity of the skull's sutures, as being the defining features between mature and developing brains. A prominent theory, supported by advances in imaging techniques, is why these developing areas render the young brain more vulnerable to injury and take longer to recover involves 'Cognitive Reserve'.(66) Cognitive Reserve describes the mature brains ability to utilize alternative cortical processes to accommodate neuronal dysfunction.(174) It has been demonstrated that such strategies are less possible in the developing brain.(14)(174) At what stage the brain begins to develop such processes remains to be fully established and makes the investigation of concussion and its cognitive effects of young populations paramount.

### 2.5.3 Genetics

Linking genetic markers with pathology has become a 'hot topic' within medical research.(175) mTBI is no exception and genetic association studies have been conducted to link specific genes to risk and outcome likelihoods. The epsilon4 allele of the Apolipoprotein E (APOE) has gained most literary traction and identified as a prognostic marker for concussion.(176) Initially identified as an Alzheimer's(177) and dementia(178) biomarker, APOE was quickly linked to severe forms of head trauma.(177) Focus has now turned towards the more prevalent milder forms, particularly within sport. By taking buccal samples of 42 collegiate athletes within three months of sustaining a concussion, Merritt and Arnett(176) found that athletes with 4 allele genotype had higher physical and cognitive impairments than those without.(176) In addition, logistic regression showed that 4 allele independently predicted those athletes who reported physical and cognitive symptoms following concussion.(176) In contrast, through the prospective, longitudinal investigation of 99 post-mTBI children, Moran *et* *al.*(179) concluded that children with epsilon4 allele did not differ on measures of post-concussive symptoms to those without. The authors conclude that allele is not consistently related to concussion outcomes in children.(179) The most recent study to link genotype and concussion risk reviewed elite level players as part of a multi-institution UK rugby genomics project.(180) Within an investigation of 635 elite level rugby union and league players compared with 722 non-athletes, Antrobus *et al.*(181) reports that elite players carry certain genetic variants that may affect stress resilience, and behavioural traits over non-athletes that alter risk of concussion incidence and severity.(181) As the authors suggest, genomics is clearly a burgeoning field and conjecture remains. As with the assessment of other risk factors, it appears hampered by the prevalence of retrospective, self-reporting symptom data within many methodologies.(175) This has led to growing scepticism of the credibility of genetic association studies.(182) Despite such challenges, identifying key factors that raise risk and prolong recovery remains relevant and will undoubtedly drive this area of research forward.

#### 2.5.4 Learning Difficulties

Published literature has identified a tentative link between learning difficulties/attention disorders and increased cognitive dysfunction and recovery times post-mTBI.(183) After pre-season baseline testing of 393 University American Footballer's, 16 players diagnosed with concussion underwent neuropsychological comparisons with matched controls by Collins *et al.*(183) The researchers found that athletes with learning disabilities and a history of concussion performed proportionally worse on selected paper and pencil neuropsychological testing than those without learning disabilities.(183) In contrast, more recently Collins, in conjunction with Lau(184), found no association between learning difficulties/ADD and protracted post-concussion recovery.(184-186) Due to this conjecture, no definitive link has been presented. What has been established, built on the strong evidence associating those with learning difficulties to poorer neuropsychological testing scores,(187) is the need for individualised neuropsychological testing. If tests are to be used to guide RTP, accounting for the effects of learning difficulties on scores needs to be considered.(14)

### 2.5.5 Previous Concussion

Several studies have found previous concussion to be a risk factor for future mTBI.(188) Within a systematic review of concussion risk factors, Abrahams *et al*.(188) found that 10 out of 13 studies across a range of sports report prior concussion as heightening future risk, following literature review.(188) The American Medical Association for Sports Medicine report an increase of between 2 - 5.8 times the risk of concussion after an initial injury.(14) Within a study of 3027 amateur rugby union players, Hollis *et al*.(189) reports the likelihood of mTBI to be almost two times higher amongst players who reported having sustained either one (IRR, 1.75; 95% CI, 1.11-2.76) or more mTBI's (IRR, 1.65; 95% CI, 1.11-2.45).(189) In addition to increasing the risk of secondary concussion, research within Soccer suggests that the risk of wider musculoskeletal injury is also heightened following mTBI.(190) Through a wide scale pan-European prospective cohort study, concussion was associated with a progressively increased risk of a subsequent injury in the first year (0 to <3 months, HR=1.56, 95% CI 1.09 to 2.23; 3 to <6 months, HR=2.78, 95% CI 1.58 to 4.89; 6-12 months, HR=4.07, 95% CI 2.14 to 7.76).(137) This phenomena is also supported by a 2-season prospective cohort study that found Professional rugby union players carried a 60% greater risk of time-loss injury within the same season, following a concussion diagnosis.(191) As with other studies, this comprehensive review of elite English rugby union concussion speculates that the cause for this finding may be a reduction in postural and neuromuscular control.(190-192) If this is the case, it may bring into question the sensitivity of current balance and gait assessment measurements. This, therefore, remains an important area for further research.

### 2.5.6 Neck Strength

Neck strength/stiffness has received growing attention within concussion research. Eckner *et al.*(193) hypothesised that in each anatomical plane, peak linear velocity and peak angular velocity of the head are inversely related to maximal isometric cervical muscle strength in the opposing direction.(193) If true, neck strength/stiffness at the moment of impact could not only be considered a reliable risk factor, but also a plausible area for injury prevention intervention.(193)(194) Recent American based research evaluated maximal isometric neck strength of 48 male and female contact sport athletes against impulsive forces in all planes of motion.(193) This laboratory-based investigation used a computational model to determine the impact of baseline neck strength and anticipatory bracing on linear and rotational velocities. The results showed that greater baseline neck strength and 'anticipatory muscle activation' reduced the magnitude of the heads kinematic response.(193) This not only implies that individuals with greater neck strength may be less like to receive concussive injury, or that they can withstand higher force thresholds, but bracing, i.e. anticipating impact and responding accordingly, could be an influential factor. This may have implications concerning the direction of force application i.e. from the rear/above/unsighted, or whether the individual has adequate time to ‘brace’ prior to impact. Such factors could have a bearing on potential game code/law amendments.

In contrast to the laboratory nature of this investigation, Collins *et al.*(194) conducted a multi-phase study attempting to determine the link between neck muscle characteristic and real world sporting concussive events. After evaluating a field measure tool of neck strength, Athletic Trainers from 51 US high schools captured pre-season anthropometric neck measurements for 6,704 athletes in boys' and girls' soccer, basketball, and lacrosse, in addition to reported concussion incidence and athletic exposure data.(194) After establishing the accuracy of the athletic trainers use of the developed tool, smaller mean neck circumference, smaller mean neck to head circumference ratio, and weaker mean overall neck strength were significantly associated with higher concussion risk.(194) In addition overall neck strength, gender and sport were significant predictors of concussions in unadjusted models. After adjusting for gender and sport, overall neck strength was reported to remain a significant predictor of concussion.(194) This research interestingly suggests that for every one-pound increase in neck strength, odds of concussion decreased by 5 % (OR = 0.95, 95 % CI 0.92-0.98).(194) This research may also support the hypothesis presented by Dick(170) and Wilcox *et al.*(195) that female athletes are more vulnerable to concussion than men.

The only study to investigate the potential effects of neck strength on concussion risk of a rugby playing population was published by Farley *et al.*(196) Isometric neck strength measurements were taken using a hand-held dynamometer from 225 Georgian based professional players at three points during the 2018/19 season.(196) Over the course of the season 30 concussions were diagnosed by club doctors. The researchers found that neck strength measurements increased during the season and there was a significant association between extension neck strength and concussion. No other anthropometric, playing variables or other neck strength aspects measured carried significant associations. The study reports that a 10% increase in extension strength was associated with a 13% reduction in concussion rate (adjusted IRR (95% CI) 0.87 (0.78 to 0.98).(196) The researchers hypothesise that the results may be linked to the extensor muscle groups ability to produce the most isometric force of all the neck muscle groups, a feature previously observed in neck strength studies.(197)(198) They suggest this may account for the extensors ability to create a 'defensive mechanism' during sagittal plane movement, the 'front on' plane most associated with concussive impacts.(199)(200) Unfortunately the researchers do not report if targeted neck strengthening protocols were used by the teams/players to this end. Despite this, the methodology used and results reported in this investigation may provide a framework for practical neck strength intervention validation. This study and the research it has built on implies that improving neck strength/stiffness is a potential area for preventative conditioning,(193)(194) a factor that warrants further investigation and is discussed further in sections 2.8.2.

### 2.5.7 Sport Type

Despite being hampered by the inherent difficulties of self-reported data and exposure definitions, incidence rates for many sports have been presented.(201)(202) Unsurprisingly, concussion appears more prevalent within sports involving higher levels physical contact.(202) Within American Football's National Football League (NFL), the sports league that has garnered the most concussion related media attention, reported incidence rates rose distinctly from the 90's to 2000's. The first league sanctioned epidemiologic study of concussion was published by the Mild Traumatic Brain Injury Committee in 2004 by Pellman *et al.*(99) Between 1996 and 2001 publicly available data was used to report an incidence rate of 0.41 concussions per NFL league game.(99) Within a descriptive study of concussion in the NFL between 2015 and 2019, Mack *et al*.(203) challenges the use of data made public by the NFL due to its limited nature. Electronic health record (EHR) data based on reports from medical staff were instead used as source material.(203) Mack *et al.*(203) reports 61.7 concussions per 100 league games over the period and a 23% decrease in the average incidence of game concussions from 2015-2017 to 2018-2019.

Comparing incidence rates between American Football and other sports has been challenging due to the games nature and subsequent incidence reporting format. Commonly, American Football concussion incidence is described per match rather than per 1000 match hours. Despite this, Lawrence *et al*.(204) reports a concussion incidence rate of 27.8/1000hrs when 2012 and 2014 NFL training and match hours were combined, commonly described in the literature as 'athletic exposures' (AE's).

In an attempt to compare concussion risk across team contact sports, Prien *et al.*(205) compiled an epidemiological systematic review. Of the 70 included studies, 53 were evaluated as moderate or high quality and included in the qualitative data synthesis to create ‘Concussion Incidence Density’ (CID) scores, in effect concussion incidence per 1000 exposures.(205) The study found the highest CID in rugby match play (3.89). This still cannot be compared suitably with American Football’s 0.30 concussions per 1000 AE’s as this data includes ‘training’ which in many studies is not fully defined and would most likely, dilute the incidence figures.

Prien *et al.*(205) appears aware of these challenges to comparing concussion data across sports. The authors state that a great number of studies were underpowered, sample populations were not sufficiently described and intervals between data collection often too long.(205) In addition, varying injury definitions were used and concussion diagnosis often relied on the clinical expertise of the data collection personnel. A commonly cited weakness of concussion incidence investigation. As described above, the authors also note the two most common exposure definitions, hours and AEs, have their own advantages, but both should be evaluated and rates reported per 1000 exposures. This did not occur in many of the included studies and no per 1000 exposure hours were reported within American Football.(205)

Within a systematic review and meta-analysis of youth sports, Pfister *et al.*(206) report that rugby (4.1/1000 AE hrs), Hockey (1.2/1000 AE hrs), and American Football (0.53/1000 AE hrs) carry the greatest risk within youth cohorts.(206) As with the adult data described above, the studies involved commonly lacked methodological, definition, and reporting metric consistency. The authors also note that gender may have influenced incidence levels but was not divided within exposure results.(206) Other sports without the depth of research included in the review, such as Taekwondo(207) and Australian Rules Football,(208) also report high incidence rates.

### 2.5.8 Rugby Specific Risk

As with most contact sports, concussion research has grown rapidly within rugby. Conducting the single broadest review of rugby union concussion to date, Fuller *et al.* (209) compiled data from elite level rugby 7's and 15's across a range of tournaments and age grades. (209) The prospective cohort study found that rugby 7's carried a significantly higher risk of concussive injury (8.3/1000hrs) than 15's (4.5/1000hrs).(209) Tackling carried the highest risk of concussion for backs in 7's and 15's formats. For forwards, tackling also carried the highest risk in 7's, however collisions presented the highest risk within 15's.(209) Rather than any physical/biomechanical cause, the heightened risk presented within 7's is tentatively accounted for through the short turnaround time between tournaments and potential player/medical primary under-reporting.(209)

As highlighted in the section 1.1, the season reports of English rugby union injuries commissioned by the RFU form one of the game's most comprehensive ongoing epidemiological investigations. The Professional Rugby Injury Surveillance Project (PRISP) was incepted in 2002/3 and covers match and training injuries across men's premiership and England senior international grades.(210) At the same time the RFU launched the Community Rugby Injury Surveillance & Prevention Project (CRISP) which collects data from men's first team grades across playing levels 3-9. The Women's Rugby Injury Surveillance Project (WRISP), British Universities & Colleges Sport Injury Surveillance Project (BUCS-ISP) and Youth Rugby Injury Surveillance Project (YRISP) followed in 2017/18 and adopted the CRISP format established in 2003.(210)

The most recent PRISP report describes the incidence of match concussion as 19.8/1000hrs.(4) Figure 2.6 below is taken from the PRISP 2019/20 report and shows the seasonal trends in match concussion incidence.

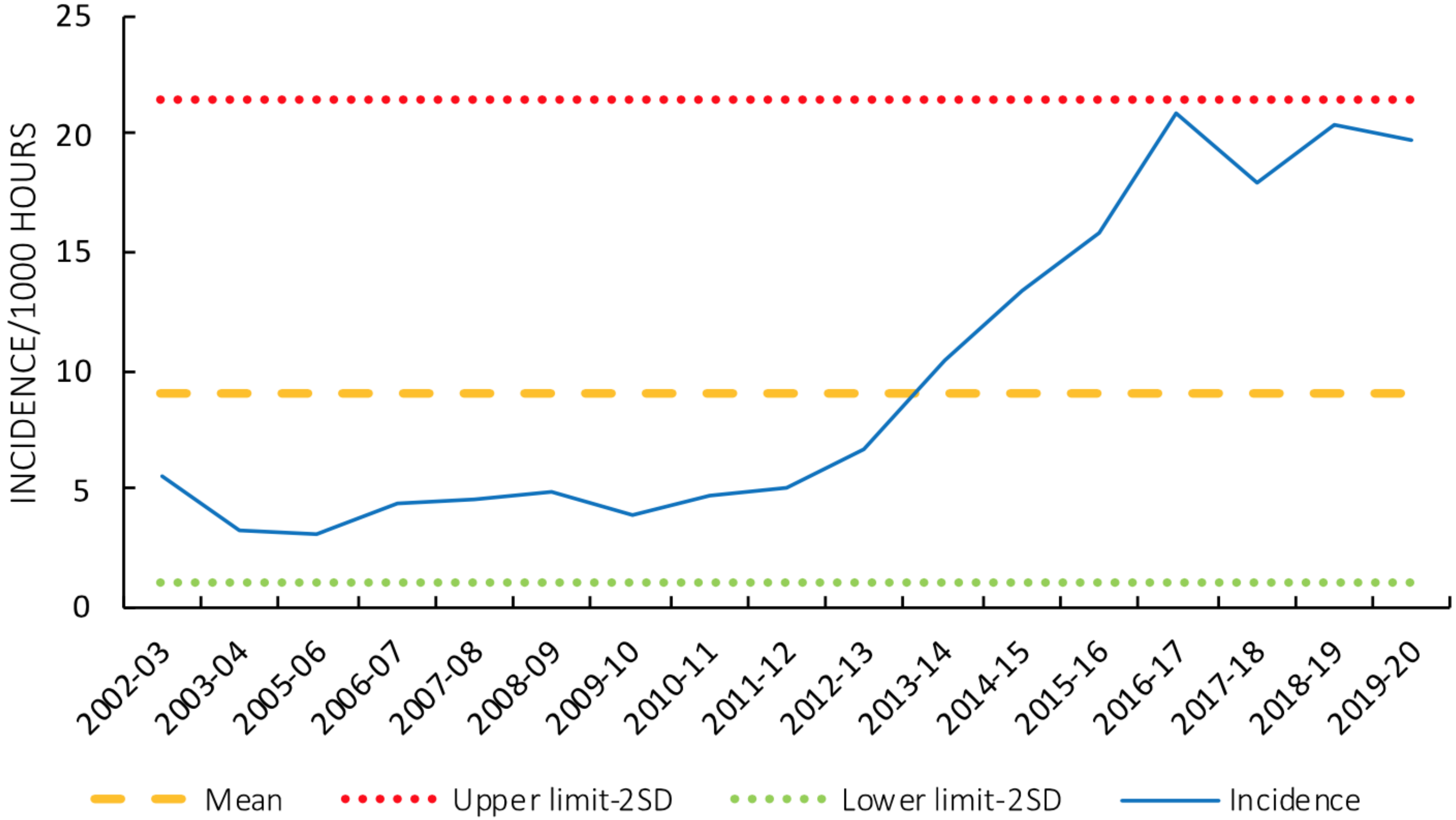


Figure 2.6 Incidence of reported match concussions by season with mean ± 2 x standard deviation shown from RFU PRISP Report 2019/20(4)

The report notes that this figure sits close to the upper limit of expected season-to-season variation, but as the graph shows, professional grade match concussion incidence levels appear to have plateaued since 2016/17 following a continued rise since 2009/10. To add context, Rafferty *et al.*(211) reports that a English based professional player in 2015/16 is more likely than not to sustain a concussion after playing more than 25 matches.(211) Considering the similarity in reported match concussion incidence between this study (21.5/1000hrs), and the latest RFU report figures (19.8/1000hrs), this assertion appears still valid. The observation of trends in concussion incidence achieved via the PRISP has been made possible by improved continuity of data collection methods and analysis. Comparison between nations however, still seems challenging. A five-season study of concussion incidence and risk factors within the French Top 14 Rugby Union Championship between 2014 and 2018 reports a combined match incidence rate of 10.4/1000hrs.(212) The last seasons (2017/18) incidence rate of 12.1/1000hrs differs markedly from the 17.9/1000hrs published within the corresponding PRISP report.(213) Unfortunately, whether the difference in these rates is due to on-field characteristics or reporting variations is hard to define. The study methodologies appear aligned as were the game laws across the leagues. Without establishing uniformity of data collection methodology, assessing if playing style which is commonly considered different between the leagues, is a concussion risk factor, remains barred.

The latest Women's Injury Surveillance Project (WRISP) mirrors the format of PRISP by following the women's English top league and international cohorts.(214) Data collection commenced alongside a reformatted top tier known as 'Premier 15's' in

2017/18 and so long-term data trends are not yet available for review. In addition, the 2019/20 season was halted in march 2019 due to the COVID-19 pandemic with incomplete training exposure data provided by four teams. This led the WRISP steering group to state that "the injury risk profile presented in the current report does not yet fully reflect the injury risk in this setting".(214) Although data management and presentation mirror the professional cohort reports, the Community Rugby Injury Surveillance Project (CRISP) pools data from rugby levels three to nine.(9) The differing playing standards, a factor reported to influence concussion risk,(9) dictates that data trends require individual and collective appraisal. The most recent CRISP report subdivides concussion incidence into three categories to achieve this. (Figure 2.7)

The 2019/20 report describes the consistent increase in reported concussions over 11 seasons for each playing level shown above. Figure 2.8 also highlights the lack of incidence level stability at lower levels, contrasting what has emerged within English professional cohorts.(4) As described above, (Section 1.1) the researchers note the challenges presented by collecting data from non-professional sporting cohorts. Despite these difficulties, continued investigation should begin to reveal trends.

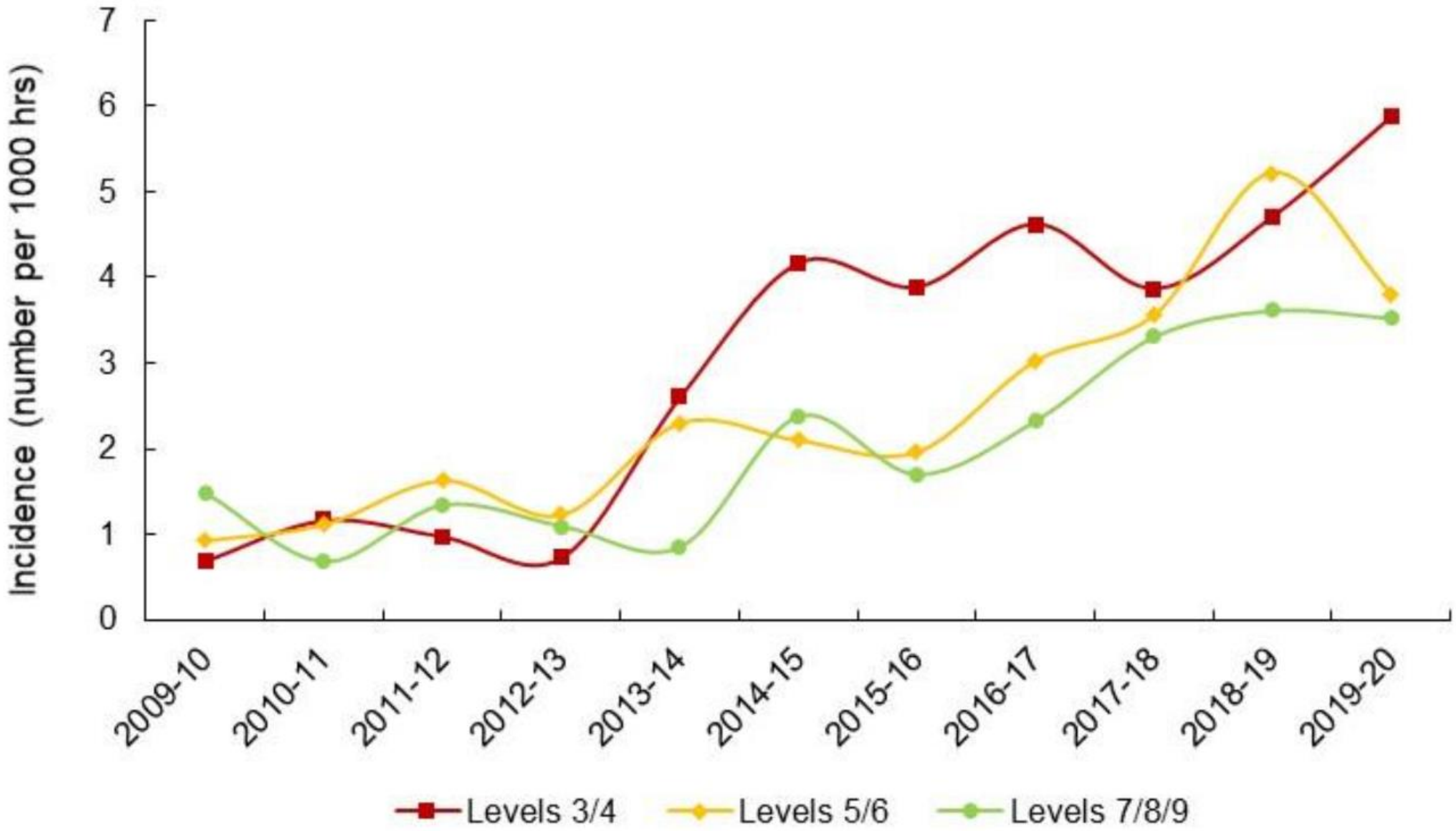


Figure 2.7 Incidence of reported concussions over 11 seasons for each playing level. From RFU CRISP Report 2019/20(9)

Within youth cohorts (<20 years), Kirkwood *et al.*(215) report concussion incidence rates ranging from 0.2 to 6.9 per 1000 player hours through the compilation of 20 rugby union and league studies. As a result, the authors conclude that both codes of rugby present "a significant risk of concussion in child and adolescent players". The authors state that a meta-analysis of the studies included was not possible due to high level of methodological heterogeneity.(215) In addition, five studies did not separate training and match data, differing injury definitions were used, and seven did not list the number of players included. The majority of studies were conducted before 2000(7) with the most recent being 2010. Despite the authors assertions, these multiple limitations leave it hard to determine an accurate level of youth rugby concussion risk from this study.

The RFU Youth Rugby Injury Surveillance Project (YRISP) has reported English male school rugby at under 13, 15 and 18 age grades for three consecutive seasons (2017/18-2019/20).(13) The RFU state that the aim of the project is to 'better understand the risk, types and mechanisms of injuries in schoolboy rugby across different age groups. This informs strategies to reduce injuries and enhance the safety of the game'.(13) The 2019/20 report includes data from 36 teams within 21 schools who volunteered to take part and also compares concussion incidence and severity across the three most recent seasons. (table 2.3 below)

Table. 2.3 Overview of concussion incidence, severity and burden across three seasons (2017-18, 2018-19 and 2019-20) from the Youth Rugby Injury Surveillance and Prevention Project (YRISP) 2019/20(13)

| | 2017-18 | | | | 2018-19 | | | | 2019-20 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Age Group | n | Incidence (/1000h) | Severity (days) | Burden (/1000h) | n | Incidence (/1000h) | Severity (days) | Burden (/1000h) | n | Incidence (/1000h) | Severity (days) | Burden (/1000h) |
| U13 | 4 | 6.0 | 22 | 135 | 0 | - | - | - | 2 | 5.2 | 34 | 177 |
| U15 | 9 | 5.8 | 25 | 144 | 7 | 4.3 | 28 | 119 | 15 | 9.2 | 24 | 221 |
| U18 | 27 | 7.4 | 33 | 246 | 44 | 11.4 | 30 | 339 | 43 | 8.8 | 28 | 242 |
| **Overall** | **40** | **6.8** | **30** | **114** | **51** | **8.7** | **29** | **255** | **60** | **8.7** | **26** | **234** |

Despite the appearance that combined youth concussion incidence rates are achieving consistency, when age groups are sub-divided, less uniformity is apparent. This is accentuated within the two younger age groups as subject numbers are lower and hence less injuries observed. At u18 level, where a larger data set has been obtained and regulations and game nature closer reflect men's rugby, a more consistent concussion profile is presented. The figure of 8.7 concussions per 1000 match hours sits above the more dated and varied studies reported within the systematic reviews of Kirkwood *et al*.(215), Pfister *et al*.(206) and Freitag *et al*.(216) All three highlight the variation in rates and potential influence of under reporting. The YRISP concussion incidence is comparable however with the reported concussions that occur in Ulster school's rugby. From 825 adolescent rugby players across 28 school first XV rugby squads, (mean age 16.9 years) 66 match and 15 training concussions were reported by Archbold *et al*.(217) The concussion incidence of 6.1/1000hrs was the first documented rate within UK youth community rugby and sits within the incidence age ranges of the YRISP. The highest incidence of reported concussion in youth rugby to date has been presented by Barden and Stokes.(218) Through a three-year review of elite English schoolboy rugby injury epidemiology, the researchers report a 20/1000hr concussion match incidence in games at the highest level of English school's competition. This is in contrast to a rate of 4/1000hrs for matches outside of the top tier competition.(218) The authors suggest that the discrepancy in findings may be a result of higher level medical cover at top tier matches. They speculate that health care professionals, mandated by the RFU to cover top tier games, may be more likely to diagnose and report head injuries than less trained stakeholders and coaches at lower levels. Weather this feature would account for the five times increase in reported concussion incidence between the cohorts is unclear. The differences do, however, highlight the wide range in figures presented and the possible factors that influence outcomes.

As with all community level injury surveillance, the results reported within school rugby must be viewed with consideration to the multiple variables that can influence reporting rates. Pitch-side medical provision, player reporting attitudes, staff data management and parental engagement, are all factors that heavily effect results. Kirkwood *et al.*(215) the RFU, and the majority of studies reporting concussion epidemiology, highlight the difficulty in accurately recording concussion incidence within sport. Without consensus in how concussion is clinically defined, diagnosed and reported, this may continue to hamper epidemiological understanding.

#### 2.5.9 Rugby Headgear

Within a range of contact sports, the impact of headgear on concussion risk has been a topic of much conjecture. The lack of high quality randomised control trials and difficulties of applying laboratory simulation to real world events has compounded matters further.(219) Understandably, not allowing potentially preventative equipment to be worn by controlled populations, in an attempt to assess its efficacy or otherwise, has proven a barrier. Expert opinion however has largely fallen into two camps within the rugby community. Those that feel that headgear does little to protect from concussive forces, with its use only serving to reduce the perceived risk and encourage dangerous play,(220) and those that feel it may serve to mechanically protect the head/skull from the milder forms of direct impact. Without implicit directive, World Rugby, rugby union's governing body and its collective unions, to suggest that the use of headgear does not reduce the risk of concussive injury. This is primarily based on the largest scale trial of headgear use conducted by McIntosh *et al.*(221) Using a cluster randomized control trial of youth age groups, totalling 1493 players (10,040 player hours), McIntosh *et al.*(221) found through intention-to-treat analysis, no differences in the rates of head injury or concussion between controls and headgear wearing cohorts.(221) These findings appear contrary to those presented by Kemp *et al*.(222) who within a three-season prospective cohort study of English Premiership rugby union head injuries, found the incidence of concussion for non-headgear wearing players significantly higher than those that wear headgear.(222) Similarly, through the study of 3027 Australian non-professional rugby players, Hollis *et al.*(189) reports an overall mTBI incidence rate of 7.97/1000hrs, in line with other similar studies, and a reduced risk of incidence for those reporting regular headgear use.(189)

### 2.5.10 Rugby Contact Nature

Historically, rugby injury research has consistently highlighted the differing degrees of injury risk that are presented by each contact aspect of the game. These have been commonly categorised as Tackling, Tackled, Collisions, Ruck, Maul, Scrum and Lineout.(213) As observed by Fuller *et al*.(209) and discussed in section 2.5.8, tackling, when the ball-carrier is held and brought to ground by a player,(223) has consistently been associated with the greatest injury risk of the contact events.(224) With approximately 200 tackles occurring during an elite level game of rugby, and head injuries being the most common injury sustained, attention has understandably fallen on this important feature for risk reduction intervention.

The first large scale investigation of rugby tackle injuries was published by leading New Zealand Rugby Union affiliated researcher Ken Quarrie in 2008. From 140,249 video recorded tackles in 434 professional level games, Quarrie *et al*.(225) found that injuries resulted most frequently from high or middle height tackles from the front or side. The rate of injury per tackle however, was higher for tackles from behind than from the front or side. Ball carriers were at the highest risk from tackles to the head-neck region, whereas tacklers, the player attempting the tackle, were most at risk when performing low tackles. The initial impact of the tackle was the most common cause of the injury with the head being the most common site. These initial findings led Quarrie *et al.*(225) to suggest that law changes surrounding the tackle may reduce injury risk.(225) Quarrie and fellow researchers have continued to investigate the nature of tackle injuries. With particular focus on the contributors to head injuries in professional rugby, a research group including Quarrie, led by World Rugby affiliated researcher Ross Tucker, performed a comprehensive video analysis of head injury events between 2013-15.(226) Tackle type, direction, speed, acceleration, nature of head contact and player body position where coded from 3624 tackle events. The 464 that led to Head Injury Assessments (HIA) were assessed in detail. The results confirmed Quarrie *et al.*(225) findings that performing active shoulder tackles carried not only the highest general injury risk, but also the highest risk of head injury specifically.(226) The study however, contradicted Quarrie *et al.*(225) early findings that tackles from behind carry greater injury risk than those from head on. The work of Tucker *et al.*(226) supported the RFU backed evaluation by Kemp *et al.*(222) in concluding that front-on tackles form the greatest risk of concussion.(222) In addition, this influential study reported that higher impacts (when a tackler is more upright) carried a four times greater risk of head injury than tackles performed when bent at the waist.(226) The findings would be used to inform World Rugby tackle law changes and awareness interventions aimed at reducing tackle height.

Building on the video analysis design employed by Tucker *et al.*(226) a group comprising of World Rugby, RFU and Welsh Rugby Union affiliated researchers took tackle associated concussion investigation further through the development of a novel machine learning model.(200) The model enabled the investigators to identify the variables that, when excluded, were associated with the largest concussion prediction error. When 182 clips of tackles that led to a diagnosis of concussion and 4619 that did not were analysed, the machine learning model identified four key areas that were most likely to impact injury likelihood.

The accelerating player, tackler speed, head contact type and tackle type proved the four characteristics that held the greatest potential for modifying the risk of concussion during a tackle. For each modifiable the authors detail the action that carried the highest concussion risk and present potential risk reducing prevention opportunities. The study highlights that head-to-head contacts carry a 40 times higher risk of concussion than a head to trunk impact.(200) As such, referee sanctioned high tackles proved 36.5 times more likely to result in concussion than a passive shoulder tackle. These findings and that of prior investigations(226)(225) have directed World Rugby's zero-tolerance drive towards head contact within rugby.(227) In addition, the study details how increased tackler acceleration and speed heighten concussion risk. The authors state that this factor may prove harder to mitigate however.(200)

The authors note that a balance between theoretical risk mitigation options and the ‘real-world landscape’, must be found. This is demonstrated in the studies stated appreciation that reducing tackle height to avoid head contact still presents heightened risk of head-to-knee and ground impacts.(200) Such events still carry an approximately 20 times greater risk than head to trunk tackles. Reducing tackle height however may present a more palatable rule change whilst still reducing concussion risk. This alludes to the challenge faced by governing bodies of contact sports to make their games as safe as possible without impacting the fundamental aspects that attract participation.

The authors also note that interventions based on player education surrounding tackle situations could also be beneficial.(200) As with all aspects of behaviour change, successful interventions of this kind rely on detailed appreciation of the knowledge and attitudes of the target individual(s). Within rugby, understanding of this nature remains limited. Despite the influential nature of this study, the authors suggest that generalisation of its results across lower levels and age grades of the game should not be made.(200) As with many aspects of sport-based research, tackle risk investigation at lower playing grades and age groups has been sparse.

Within the first study to assess the association between rugby tackle characteristics and injury outside of professional levels, McKintosh *et al.*(228) found that the level of the game, under 15, under 18, under 20, adults and elite grades, carried increasing risk of tackling injury.(228) In line with subsequent injury epidemiology studies including Cross *et al*.(200) described above, the authors reflect that generalised risk assumptions across levels should, therefore, not be made.(228) From the 6618 tackle events analysed by video, active shoulder tackles (where the shoulder is the first point of contact and forward momentum ensues) and smother tackles (arms wrapped around the ball carrier trapping the ball), performed more frequently at adult levels, carried greater injury risk. This study would help form the core tackle characteristic understanding built upon by World Rugby engaged research groups.(228)

In addition to the 2010 publication by McKintosh *et al*.(228) only one other study including head contact event nature in youth rugby has been published. Hendricks *et al.*(199) developed a novel proficiency score to grade the completion of various contact events within South African under 18 games.(199) Video footage of 10 concussive events (5 tackle, 4 ruck and 1 aerial collision) and 83 NI events were identified. The researchers analysed the events with reference to a criterion developed from the work of Australian sport scientist Tim Gabbett and associates.(229) (see Table 2.4 below)

Table 2.4 Front-on tackle contact proficiency scoring criteria from Hendricks *et al.* (199)

| | Front-on tackle |
|---|---|
| Bally-carrying proficiency | *Pre-contact*<br>Eyes focused on tackler<br>Shifting the ball away from contact<br>Body position - upright to low body position<br>Body position - straight buck<br>Head up and forward, eyes open<br>Shuffle or evasive manoeuvre<br><br>*Contact*<br>Fending into contact<br>Side-on into contact<br>Explosiveness on contact<br>Body position - from a low body position up into contact<br>Ball protection<br><br>*Post-contact*<br>Leg drive upon contact<br>Arm and shoulder usage<br>Go co ground and present ball |
| Tackling proficiency | *Pre-contact*<br>Identify/track BC onto shoulder<br>Body position - upright to low (dipping)<br>Straight back, centre of gravity forward<br>support base<br>Square to BC<br>Boxer stance (elbows close, hands up)<br>Head up and forward<br>Shortening steps<br>Approach from front/oblique<br><br>*Contact*<br>Explosiveness on contact<br>Contact with shoulder opposite leading leg<br>Contact in centre of gravity<br>Head placement on correct side of BC<br><br>*Past-contact*<br>Shoulder usage (drive into contact)<br>Arm usage (punch forward and wrap i.e.hit-and-stick)<br>Leg drive upon contact<br>Release BC and compete for possession |

BC=Ball Carrier

The study reported lower than average proficiency scores for contacts that led to diagnosis of concussion.(199) Despite recognised limitations in subject numbers, such findings support the notion that poor contact technique is an injury risk factor across the wider rugby playing community.(199)(230) Despite further research required at community and youth levels, researchers and governing bodies continue to build the means to evaluate game related concussion risk factors and ways to address them whilst minimalising the impact on rugby's core characteristics.

### 2.6 Assessment

The assessment of SRC is a vital component in head injury management. Consensus has yet to be achieved as to gold standards and novel formats are frequent within the literature. Biomarkers, diagnostic imaging and the spectrum of neuro-psychological/Physical assessments currently in use are discussed below. The appraisal and novel use of the K-D Test to address current limitations in rugby head injury assessment forms a core aim of this thesis.

#### 2.6.1 Biomarkers

To date, identifying biomarkers associated with the functional disruption associated with mTBI, below the level that might lead to positive CT or MRI findings, has proved challenging. Despite these challenges, it remains an area of profound importance and as such, has received extensive funding worldwide.(231) Several potential substances have been linked to head injuries that associate with abnormality on imaging, however these have proved to either not link with functional brain outcomes, or not present in less severe head injury cases.(25)(232) Despite this, several blood-based biomarkers have recently been characterised that may, in combination with imaging and neuropsychological techniques, lead to effective diagnosis and prognosis.(80)

The basis for biomarker evaluation has largely been in the assessment of the release of proteins from degenerating neurons.(233) Researchers recently identified four particular proteins, Copeptin, Galectin 3, Matrix Metalloproteinase 9 and Occludin, whose bloodstream levels were distinctly altered within post concussive head injury patients. By comparing these levels with those seen in a control group and a post orthopaedic injury group, the researchers were able to identify common patterns seen solely following mTBI.(234)

Tau Protein, highly linked with axonal damage, is also considered to be present in altered levels following mTBI and is widely established as a focus for chronic TBI diagnostics.(235) Differing fragments of this microtubule stabilising protein have been observed following sports related concussions. Within a study of 288 Swedish professional Ice Hockey players, Shamin *et al*.(22) observed higher levels of Tau-C following 35 concussive events and Tau-A levels appeared to correlate successfully with on-going recovery rates. This study suggests that this biomarker may be suitable in predicting safe RTP.(22)

The protein S-100B, associated with calcium binding and neuron specific endolase (NSE), has also been speculated as a potential correlative marker,(235) but has been criticised for lacking strong correlation with functional brain outcomes.(80) To address these deficiencies, the identification of suitable blood biomarkers has begun to centre on the recording of combinations of proteins released during neuro-degeneration. Siman *et al.*(2013)(80) demonstrates that αII-Spectrin N-Terminal fragment (SNTF) a Calpain cleaved proteolytic fragment, known to be found in higher concentrations in the blood of patients following severe TBI, may also be a practical marker for those with milder head injuries. Through correlation with Diffusion Tensor imaging (DTI) and three cognitive impairment measures, Siman *et al.*(80) evaluated 17 patients diagnosed with mTBI, 13 orthopedically injured patients, and eight un-injured subjects. The study found that SNTF levels correlated significantly with imaging techniques and cognitive tests on the same day of injury for those diagnosed with mTBI.

Establishing the most accurate Biomarker for mTBI assessment is, however, only half of the challenge faced by researchers. If and when a suitable biomarker is found, if it cannot be assessed pitch-side, it's utility within sports medicine will be minimal. Appreciating this constraint, the most recent concussion biomarker research has put practical application at its methodological core. By establishing a biomarker that is accessible pitch-side first, and then searching for how it might be affected by mTBI, research breakthroughs are on the horizon. Saliva has become the leading pitch-side candidate. The next steps have been to identify a measurable molecule specific to neuronal injury, small enough to cross the blood-brain barrier and into peripheral fluids. Research interest has focused on MircoRNA (miRNA) molecules. MiRNA's are short, non-coding ribonucleic acids that can regulate protein translation in response to brain injury.(236) Unlike proteins that can degrade in the mouth, miRNA's demonstrate relative stability in saliva.(236) Although limited by small subject sizes and burgeoning methodologies, early studies results indicated changes in miRNA following neural disruption,(237) with a degree of sensitivity to injury severity.(238)

The first large scale investigation of an miRNA diagnostic utility within sports concussion was developed by the University of Birmingham's REpetitive COncussion in Sport (RECOS) project.(239) In conjunction with the RFU and Rugby Players Association (RPA), all Premiership and Championship level players during the 2017/18 and all Premiership players during the 2018/19 had saliva samples taken for analysis. Samples were collected pre-season from 1028 players and during 156 standardised HIA's (in-game, post-game, and 36–48 hours post-game). In addition, control samples were collected from 102 uninjured players and 66 players who sustained a musculoskeletal injury. Diagnostic small non-coding RNAs were identified with next generation sequencing and validated using quantitative polymerase chain reaction (PCR) in 702 samples.(239) A predictive logistic regression model was then built by the researchers using 2017/2018 data which was prospectively validated the following season. Following clinical assessment, concussion was confirmed (HIA+) in 106 players and ruled out (HIA−) in 50 players during matches. The researchers initially identified 32 different sncRNA markers across the three time points that were differentially expressed in HIA+ rugby players compared with HIA- players after examination. After data analysis, 14 different biomarkers that accurately predicted clinical diagnosis of concussion in professional rugby players were established.(239) The researchers suggest that these initial findings, despite being localised to professional cohorts, could form the basis for the development of new pitch-side objective diagnostic tools.(239) Prior to the studies inception project lead and Neurosurgeon, Professor Tony Belli stated that,

*"If these biomarkers are found reliable, we can continue our work with industrial partners with the hope to have a device available within the next two years that will instantaneously diagnose concussion on the pitch-side with the same accuracy as in the laboratory - a major step forward for both sport and medicine."*(240)

Saliva testing may also reveal more about the long-term consequences of sub-concussive events.(241) Clearly further research in this field is required, however this study presents an optimistic outlook for saliva-based assessment. Investigation at lower levels and age graded rugby is needed and routine use of this assessment method may take many years of development. In addition, if a saliva-based assessment is not financially viable within community sport, it may well remain a niche tool reserved for elite level applications diminishing its promise.

### 2.6.2 Diagnostic Imaging

As discussed above, undoubtably, the gold standard means of assessing mTBI/concussion would include some form of objective, practical, physiological measure. Three primary avenues of research are being pursued to this end: 1) blood, serum, CSF and saliva biomarkers as discussed above, 2) developments in existing imaging techniques discussed below, and 3) Occulo-motor assessments (section 2.6.4)

Imaging following concussion remains rare despite the frequency of patients attending hospital emergency departments. Conventional imaging techniques rarely show observable pathology and therefore, provide little benefit in the majority of cases.(242) Clinical indications to scan range from region to region but usually consist of reduced Glasgow Coma scale scores, prolonged loss of consciousness and physical signs of injury such as bleeding.(243) As few mTBI patients have these symptoms, most are assessed solely by symptom review and cognitive function tests. Despite this, developments in imaging techniques have been presented that assist in the evaluation of other diagnostic tools and may become more routinely applicable in the future.(244) Conventionally, Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) have historically been presented as the only viable options in assessing structural head injuries.(132) Their lack of sensitivity to the milder forms of traumatic injury, where structural changes are subtle, in conjunction with inherent exposure issues, has limited their use. Enhanced neuro-imaging techniques have, however, been pioneered which may prove more effective.(244)

Diffuse Tensor Imaging (DTI) is a technique developed from DWI – Diffusion Weighted Imaging, a particular sequence of MRI. Prior to its use to within traumatic brain injury it has been used to examine white matter changes associated with Multiple Sclerosis, Stroke and Parkinson's disease.(245) Unlike conventional MRI, it is sensitive to microstructural changes in white matter tracts following mild brain trauma.(246) It is based on assessing the direction of diffusion of water molecules altered following axonal disruption.(245) Because of the relative infancy of this technology its use within clinical studies has been limited. Despite this DTI's ability to observe previously unseen changes in white matter may make it a vital tool in correlating other, more readily available tools and we may see its use become more common in hospital settings and sports medicine.(247)

Functional MRI is based on the assessment of brain function through blood flow within the capillary beds of the brain. The addition of Blood Oxygenation Level Dependent (BOLD) sequences, also known as Susceptibility Weighted Imaging (SWI), were pioneered in the early 1990's and have been used to measure relative levels of oxygen within cerebral blood.(248) Oxygen levels change following the increased hemodynamic drive that damaged neurons present. As such fMRI BOLD has been used in a limited group of studies to correlate altered cerebral blood markers with a variety of cognitive function impairments following mTBI.

Consensus findings indicate differing areas of cortical activity following sporting mTBI than in control populations.(123) It has, therefore, been hypothesised that the brain is 'compensating' for areas of neuronal dysfunction by activating other regions.(123) This led researchers to evaluate the link between the adverse cortical activity observed and specific functional impairments. Johnson *et al*.(249) compared a battery of occulo-motor tests to simultaneous fMRI scans of 15 concussed participants. Results showed that comparatively poor performance of three occulo-motor tests, compared with normal populations, correlated directly with adverse fMRI findings. In addition, on 30-day follow-up tests the concussed groups scores closely mirrored that of the non-concussed participants, demonstrating recovery.(249) This study seems to indicate that not only is fMRI a sensitive tool in detecting cortical impairment but also correlates to more practical, applicable assessment tools such as occulo-motor screening.

In addition to the innate limitations that fMRI carries, it has also been noted that the majority of the investigations are performed sub-acutely, have limited ability to directly reveal functional significance and do not encompass a wide spectrum of age groups.(250) In addressing this last limitation, Keightley *et al.*(174) has added to the growing body of paediatric specific mTBI research that has incorporated fMRI.(174) Through the study of 15 concussed youths and 15 control subjects, significant alterations in brain activity were observed on fMRI BOLD tests that linked directly to reduced neuropsychological and behavioural tests within concussed subjects. These results support previously established findings within adult populations. Intriguingly, distinct differences were seen between the previous adult investigations and those for younger participants. Keightley *et al.*(174) observed reduced working memory accuracy which they suggest shows that youths may be unable to engage compensatory strategies, also known as cognitive reserve, to maintain cognitive performance after mTBI. They speculate that this may have implications for the establishment of safe return to daily activities and sport.(174)

Arterial Spin Labelling (ASL) has also emerged as a result of developments in fMRI technology. Similarly to the above techniques it examines cerebral perfusion, using arterial blood water as an endogenous contrast agent.(123) The few studies conducted to date have revealed global, regional and diffuse reductions in CBF following mTBI.(251) Through the use of ASL Wang *et al*.(252) compared the CBF of post-concussion American Football players with SCAT3 and SAC scores.(252) Whilst the conventional testing measure scores returned to baseline levels within eight days, CBF levels were significantly reduced for those concussed over that of control participants.(252) This appears to indicate that physical changes may persist past the normalisation of commonly observed clinical symptoms.

Imaging has a significant role to play in improving our understanding of mTBI. Although not a practical pitch side tool, it holds the key to determining the link between physical, observable pathology and the neurological and behavioural features that so many people present with. In addition, the specific evaluation of paediatric populations, where the brain is still developing, may be a key area that imaging based study can benefit.(123) Imaging in its various forms may also enhance our understanding of the timescales and nature of the recovery process following mTBI as shown above. This may lead to novel intervention strategies and could influence RTP guidelines.(245) Until practical accurate means of establishing mTBI with the use of physiological markers, we are however left with a reliance on conventional symptom testing in acute instances.

**2.6.3 Neuro-psychological/Physical**

Neuro-psychological and symptom evaluation forms the cornerstone of concussion diagnostics in the absence of practical biomarkers.(253) The Sports Concussion Assessment Tool 5 (SCAT5) devised by the Concussion in Sport Group (CISG) is accepted by many sports governing bodies as the current gold standard assessment tool.

The SCAT3 is divided into two areas; Side-Line Evaluation and Cognitive and Physical Examination. Side-Line evaluation currently includes the Glasgow Coma Scale and the Maddocks Questions.(30) The Maddocks Questions, as discussed above and listed below (Table 2.5), are designed to assess working memory deficits. A child version was also introduced as part of the Child-SCAT3 evaluation.(254)

Table 2.5 Adult and Child Maddocks Questions.(30)

| Adult Maddocks Questions (over 12 years) | Child Maddocks Questions (5-12 years) |
|---|---|
| At what venue are we today? | Where are we at now? |
| Which half is it now? | Is it before or after lunch? |
| Who scored last in this match? | What did you have last lesson/class |
| What did you play last week? | What is your teacher‘s name? |
| Did your team win the last game? | |

The sensitivity of the Maddocks questions has been open to criticism. In a more recent study of elite level AFL players over four seasons by Makdissi *et al.*(255) concussive injuries were observed in 158 players over 640 games. With 26 games per team per season, an average of 8.08 concussions per season occurred,(255) double the amount reported by Maddocks *et al.* in his underpinning research. If the risk of concussion in AFL play is perceived to have changed minimally in this time, the only plausible explanation for such a stark difference must be in the diagnostic sensitivity of those players deemed concussed. In both examples, symptom reporting to medical staff and observation were the basis for diagnosis, as was the convention at the time. This not only highlights the difficulties of injury frequency assessment within concussion, but also more importantly brings into question the sensitivity of Maddocks original findings. If this study only included those diagnosed with concussion at the higher end of an injury severity scale, as more recent epidemiological study suggests,(108) it may not be possible to generalise the participant's orientation responses to our now broader spectrum. This may mean that the questions lack suitable sensitivity. Considering the prevalence of the Maddocks Questions use in sports related concussion, this would seem a highly important area for further investigation.

The main body of the SCAT assessment, designed to be completed following removal from play, incorporates the Standardised Assessment of Concussion (SAC), A self-reported symptom evaluation, neck examination, balance examination and co-ordination examination; all components previously devised and used independently.

### 2.6.4 Standardised Assessment of Concussion (SAC)

The Standardised Assessment of Concussion (SAC) was developed to provide clinicians with a more objective and standardised method of immediately assessing an injured athlete's mental status.(256) Intended for use on sport side-lines following suspected concussion, the instrument is intended as a supplement to other methods of concussion assessment such as neuro-psychological evaluation, postural stability testing, but not as an independent measure.(256) Now incorporated into the SCAT, the SAC comprises Orientation Assessment, Immediate Memory Assessment and Concentration Assessment shown below. (Figure 2.8) Orientation Assessment (AS) is based on the same premise as the Maddocks Questions that short-term memory function is impaired in those with concussion. The AS differs in that it is non-sport specific.

The immediate memory (IM) component of the SAC comprises of three repeated word recall tests. Based on the premise that working memory impairments are associated with mTBI,(128) the recalling of word lists have been deemed suitable in assessing such deficits.(257) The Concentration Assessment (CA) component involves the recall of a set of numbers but in backward order. CA also involves recall of the months of the year in reverse, the Months Backwards Test (MBT). Through systematic review, Meagher *et al.*(258) reports that the MBT is a simple, versatile and sensitive tool. Despite this they also state that normative MBT scores within youth populations differ widely. No evidence exists that this is any different with number or word recall.

**Table 2. Standardized Assessment of Concussion (SAC)**

**1) Orientation:**

| | | |
|---|---|---|
| Month: ______ | 0 | 1 |
| Date: ______ | 0 | 1 |
| Day of week: ______ | 0 | 1 |
| Year: ______ | 0 | 1 |
| Time (within 1 hr): ______ | 0 | 1 |
| **Orientation Total Score** ______ | / | 5 |

**2) Immediate Memory:** (all 3 trials are completed regardless of score on trial 1 & 2; total score equals sum across all 3 trials)

| List | Trial 1 | | Trial 2 | | Trial 3 | |
|---|---|---|---|---|---|---|
| Word 1 | 0 | 1 | 0 | 1 | 0 | 1 |
| Word 2 | 0 | 1 | 0 | 1 | 0 | 1 |
| Word 3 | 0 | 1 | 0 | 1 | 0 | 1 |
| Word 4 | 0 | 1 | 0 | 1 | 0 | 1 |
| Word 5 | 0 | 1 | 0 | 1 | 0 | 1 |
| **Total** | | | | | | |

**Immediate Memory Total Score** ______ / 15

(Note: Subject is not informed of delayed recall testing of memory)

**Neurologic Screening:**

*Loss of Consciousness:* (occurrence, duration)

*Retrograde & Posttraumatic Amnesia:*
(recollection of events pre- and post-injury)

*Strength:*

*Sensation:*

*Coordination:*

**3) Concentration:**

*Digits Backward* (If correct, go to next string length. If incorrect, read trial 2. Stop after incorrect on both trials.)

| | | | | |
|---|---|---|---|---|
| 4-9-3 | 6-2-9 | ______ | 0 | 1 |
| 3-8-1-4 | 3-2-7-9 | ______ | 0 | 1 |
| 6-2-9-7-1 | 1-5-2-8-6 | ______ | 0 | 1 |
| 7-1-8-4-6-2 | 5-3-9-1-4-8 | ______ | 0 | 1 |

*Months in Reverse Order:* (entire sequence correct for 1 point)

| | | | |
|---|---|---|---|
| Dec-Nov-Oct-Sep-Aug-Jul Jun-May-Apr-Mar-Feb-Jan | ______ | 0 | 1 |
| **Concentration Total Score** | ______ | / | 5 |

**Exertional Maneuvers**
(when appropriate):

5 jumping jacks — 5 push-ups
5 sit-ups — 5 knee bends

**4) Delayed Recall:**

| | | | |
|---|---|---|---|
| Word 1 | | 0 | 1 |
| Word 2 | | 0 | 1 |
| Word 3 | | 0 | 1 |
| Word 4 | | 0 | 1 |
| Word 5 | | 0 | 1 |
| **Delayed Recall Total Score** | ______ | / | 5 |

**Summary of Total Scores:**

| | | | |
|---|---|---|---|
| **Orientation** | ______ | / | 5 |
| **Immediate Memory** | ______ | / | 15 |
| **Concentration** | ______ | / | 5 |
| **Delayed Recall** | ______ | / | 5 |
| **Overall Total Score** | ______ | / | 30 |

Figure 2.8 Standardised Assessment of Concussion (SAC).(257)

The SAC test was initially designed to be compared against a pre-recorded baseline score.(256) This would negate any concerns that the AS component may record false positive results if a participant did not know the date or time of day. This would also negate the wide range of normative scores seen within youth MBT test.(258) The SCAT series of tests, with the SAC within, is not, however, promoted in practice as a test that requires a baseline. Whether this creates validity issues for the SAC's current use remains highly debatable. The wider correlation of SAC results to concussion has been also brought into question. By comparing SAC scores with CT findings of patients following traumatic head injury, O'Neil *et al.*(259) found similarly positive CT findings with high and low SAC scores. As such, the research group state that normal SAC scores do not exclude intracranial injury.(259) The correlation for milder forms of traumatic injury to SAC scores was significant however, by the developers of the tool.(260)

### 2.6.5 Balance/Vestibular assessment

Balance disturbances are a commonly observed sequale of concussive head injury.(261) Initially assessed using laboratory based force plate and motion detection technology, the Balance Error Score System (BESS) developed by the University of North Carolina, aimed to negate the need for such equipment and provide a formalized practical tool.(262) The BESS is cited as an inexpensive, non-instrumented test consisting of 6 separate 20-second balance tests performed in 3 stance conditions (double-leg, single-leg, and tandem stance) on 2 different surfaces (firm and compliant). For the single-leg stance, the non-dominant leg is selected.(263) Following systematic review, the BESS showed moderate to good reliability to assess static balance.(263) Low levels of reliability have, however, been reported.(263) The tool has also been cited to be sensitive to subjectivity in scoring and learning effects.(28) In addition, its accuracy has been questioned following day three post injury.(264). Regardless of these validity concerns, its use has been consistent within the SCAT series of concussion assessments despite modification.(265) Attempts have been made to negate the subjective nature of the assessment by combining its use with objective means. Alberts *et al.*(266) developed the iBESS by incorporating the use of a computer tablets gyroscope feature. This added quantitative data to the conventional pass/fail scoring of the BESS. Similarly, Rhine *et al*.(267) evaluated the use of the Wii balance board within paediatric concussion.(267) The most recent technological addition to vestibular assessment has come from the US based hearing and balance technology company Natus. Through the development of ICS Impulse, a digital pair of glasses, (see figure 2.9 below) Natus can record a range of balance measures in addition to oculomotor function.(268) The ICS Impulse system is beginning to be evaluated within post sports concussion participants(269) and may become more widely used in concussion recovery. Such innovative tools may point towards practical adjuncts that negate some of the current concerns of balance testing. With refinement, balance assessment could be considered as part of a battery of tools in acute concussion management.


Figure 2.9 Natus ICS Impulse - Vestibular Testing System

### 2.6.6 Coordination

The SCAT assessment tools include an assessment of co-ordination in the form of the Finger to Nose Test (FTN). Derived from the classic neurological assessment for dysmetria, dyskinesia and tremor, the protocol is reported to provide a global and objective measure of upper limb coordination.(270) Normative values and comparisons between FTN and postural control measures have been established,(29) along with the impact of exercise on performance.(271) Despite this, specific investigation of the impact of mTBI/concussion on FTN performance, and, therefore, its validity as a concussion measure, remains unpublished despite its consistent inclusion within the SCAT series of tools.

### 2.6.7 Sports Concussion Assessment Tool (SCAT)

The elements described above form the core of The Sports Concussion Assessment Tool (SCAT). SCAT is a paper based neurocognitive assessment initially devised with the involvement of FIFA and the medical arm of the International Olympic Committee (IOC).(272) The tool was developed for use by doctors, therapists, health professionals, coaches, and other people involved in the care of injured athletes, whether at recreational, elite or professional levels.(21) The SCAT2, an updated version was released by the CISG in 2008.(21) Now with the inclusion of the International Rugby board (IRB), now known as World Rugby, The SCAT2 was created to ensure this key documents production, and that of the wider consensus statement, adhered to the guidelines set forth by the US National Institutes of Health for formal consensus agreement.(21) A pitch-side quick concussion check card called ‘Pocket SCAT’ was also introduced. The Consensus

Statement and SCAT tool was criticised with questions raised over the evidence base to constituent components.(273)(274) To evaluate the methodological rigor underpinning the consensus statement, White *et al.*(273) utilized the Appraisal of Guidelines for Research and Evaluation (AGREE-II) tool. Despite endorsing the consensus statement, the independent appraisal surmised that modifications were needed.(273) The CISG revised the SCAT2 after 4 years of use and published the SCAT3 in 2013. Several amendments were made including the removal of the original composite score which was considered not suitably evidenced.(275) In addition, the physical and objective signs list was amended, the Maddocks questions removed from the long form and modifications to the balance components were made.(276) In addition, a child specific version (Child-SCAT3) was introduced designed for children between 5 and 12 years old.(254) Normative values for SCAT2 and 3 have also been presented which may add greater context to post-injury scores.(254)

Following the International Consensus Conference on Concussion in Sport held in Berlin in 2016, the CISG published the most recent iteration of the series, the SCAT5, The following year.(116) This was accompanied by an updated child version, the Child-SCAT5(277) and as the SCAT5 remained solely intended for use by medical professionals, the Concussion Recognition Tool 5 (CRT5), an abridged tool for non-medically trained individuals.(115) Table 2.6 lists the amendments introduced below.(115)

The modifications included in the SCAT5 have not gone without critique. In a review of the diagnostic utility of the new neurological screen sub-tests, Fuller *et al.*(278) and fellow World Rugby associated colleagues, conclude that the new comprehension, passive neck movement, and diplopia sub-tests performed worse than other SCAT sub-tests leading to no additional value.(278) They state that the very low sensitivities observed from a prospective cohort study of Pro14 elite rugby union players, indicate that they could not be substituted for other SCAT5 components.(278) In addition, World Rugby linked researchers evaluated the effects of exercise on baseline SCAT5 performance.(279) Through the conduction of a cross-sectional study of 698 male professional rugby players, differences in SCAT5 performance at rest were compared to SCAT5 conduction after 30 minutes of exercise. The results showed significant differences in reported symptoms, cognitive sub-test performance and balance sub-test performance. Players were either assigned to a group that performed the test at rest (RSCAT), followed by the exercise-test protocol (EXSCAT), or a group where the EXSCAT was performed first and then RSCAT.(279)

Table 2.6 SCAT modifications from Echemendia *et al*.(2017)(115)

| | SCAT5 Modifications |
|---|---|
| 1 | Declaration that the complete SCAT5 cannot be appropriately completed in less than 10 min. |
| 2 | Inclusion of an Immediate Acute Assessment section, including indications for emergency management and observable signs of possible concussion. |
| 3 | Clarified instructions that the Symptom Checklist should be completed by the athlete in a resting state. |
| 4 | Different instructions for completing the symptom checklist at baseline and postinjury have been added. |
| 5 | Addition of questions that compare the athlete's post-injury presentation with pre-injury behaviour. |
| 6 | The SAC immediate and delayed word recall lists include an option to use 10 words instead of 5 to minimise ceiling effect. |
| 7 | All six versions of the SAC word lists are now presented with alternate stimulus sets for the word list and digits backwards. Their administration should be randomised at baseline and serially post-injury. |
| 8 | A notation of when the last trial of the word list was administered is required (the delayed recall should not be administered sooner than 5 min after the immediate memory sub-test). |
| 9 | Digits Backwards now contains six versions of the digit strings which should be itemised at baseline and serially. |
| 10 | A Post Neurological Screen has been included. |
| 11 | A section has been added that includes affirmation that the SCAT5 was used or supervised by a healthcare professional and whether a concussion was diagnosed. |
| 12 | The instruction section has been enhanced to include all of the modifications described above. |
| 13 | The Return to Sport progression emphasises that the initial period of physical and cognitive rest should typically only last 24-48 hours. |
| 14 | A Return to School progression has been added, including possible academic accommodations. |
| 15 | The SCAT5 specifically indicates that written clearance by a healthcare professional is necessary prior to returning to play/sport |

In order to evaluate any learning effect from the tests, RSCAT-EXSCAT participants mean time between tests was 0.03 days (IQR 0.02-1.09) whilst the EXSCAT group had longer between tests (3.03 days IQR 0.96-8.87).(279) The results indicated that, in addition to symptom reporting being higher when assessed immediately after exercise compared to rest, a learning effect was apparent when test conduction was closer together. In addition, balance error scores also worsened after exercise. The researchers state that these findings require greater exploration and future studies would ideally include participants that experience head injuries. Such research may help define what conditions the SCAT baseline assessment should be conducted under and the frequency of baseline tests.(279)

As with many consensus statement processes, the creation of rigorous guidelines and recommended tools can be complex.(280) Such rigor relies on the strength of evidenced used.(273) This has meant that the consensus statement and SCAT tools have had to evolve(132) as evidence builds in a fast paced research environment. Despite this, a commonly cited criticism remains the time the SCAT tool takes to complete. Reported to take between 10-25 minute,(281)(282) if self-reported rates of head injury continue to rise the time burden placed on the intended users; doctors, therapists, health professionals and coaches, could become prohibitive and thus further challenge its use. In addition to criticism regarding the SCAT assessments, the CISG has also experienced media and governance scrutiny. In February 2022 the CISG chairman Dr Paul McCrory stepped down from his post following substantiated accusations of plagiarism.(283)(284) The heightened attention on the CISG and his role provoked renewed financial conflict of interest's accusations levelled at the group and world sport governing bodies.(283)

Within its third publication in 2021, this led the UK Government Digital Culture Media and Sport (DCSM) Committee to question the reliance on the CISG's guidelines and recommend the UK instigate a new independent UK concussion advisory group.(285) Due for publication in late summer 2022, the DCMS Concussion in Sport recommendations are likely to define this and other concussion risk reduction directives.

**2.6.8 Computer Based Assessments**

Computer based baseline and post-concussion assessments have been in use for the last 20 years.(286) In this time, the most popular programmes have become the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)(287), CogState Computerized Assessment Tool (CCAT)(288), Automated Neuropsychological Assessment Metrics (ANAM®)(289), and CNS Vital Signs.(290) As with paper based tools, Computer-based testing can be used to establish a pre-injury baseline of neurocognitive function and then measure potential neurocognitive change post- injury. Computer based testing however, can also include using auditory and visual elements. In addition, computer-based assessments can be used for large groups with data available without additional processing.(291) The inherent drawback of computer-based testing remains its reliance on technology and device availability, although developments in smart phone and tablet-based formats may promote wider use.

The 2020 North American College Athletic Association (NCAA) review of the Sensitivity and Specificity of Computer-Based Neurocognitive Tests in Sport-Related

Concussion(291) forms the modes most current validation. The report concludes that no assessment or interpretative approach was substantially better than another. Sensitivity and specificity results were low for all tests indicating the need for further development within this field.(291)

**2.6.9 Head Injury Assessment (HIA)**

Within elite level rugby union, the pitch side assessment of concussion differs from that of lower levels. The Head Injury Assessment (HIA), sanctioned for use by World rugby during 2015, comprises of three sections; HIA1 pitch side evaluation observed by an independent Match Day Doctor (MDD), HIA2 (based on the SCAT3) and HIA3, a continued symptom evaluation assessment. The pitch side evaluation comprises of the Maddocks Questions, The SAC, a tandem stance gait test and a symptom score. A player that is suspected of sustaining concussion is removed from play, and the test conducted within a 10-minute window. Following commissioned research completed in 2012/13, World rugby confirmed that prior to the introduction of the HIA, 56% of players with a confirmed concussion had returned to the field of play. Following the introduction of the HIA tool and process, this number had dropped to below 12%. (292)

Guidance from World rugby states that players diagnosed or suspected of sustaining concussion undergo a one-week period of ‘rest’, cited as the ‘cornerstone of concussion treatment’, prior to commencement of the GRTP.(293) This period is increased to 2 weeks for players less than 18 years of age. World rugby states that this is a minimum and it is at the discretion of individual unions to recommend more stringent criteria.(293)

The RFU have chosen to do so and have deemed 2 weeks rest for adults suitable.(18) Despite these guidelines, exceptions to this 'cornerstone' process prevail at elite levels, where access to brain imaging and trained multidisciplinary practitioners is deemed sufficient to negate the need for a mandatory rest period. (See below)

The RFU state that for an abbreviated RTP protocol to be used a player must have access to;

*a)* *A doctor with training and experience in the management of concussion/traumatic brain injury available to closely supervise the player's care and GRTP, and clear the player prior to RTP.*

*b)* *A structured concussion management programme including Baseline SCAT 3 and/or Computerised Psychometric/Cognitive testing.*

*c)* *Clinical serial multimodal concussion assessment of players post head impact event.*

*d)* *Formalised GRTP programme with regular SCAT 3 or equivalent assessments recorded in players' medical records.*

*e)* *Access to neuropsychology/neurology/neurosurgery specialists if required.*

*f)* *Formal concussion education programme for coaches and players.*

It is suggested that professional clubs and rugby academies may meet these criteria however a formal accreditation process is not in place.

The RFU policy and that of the HIA has drawn criticism from within the sport and wider fraternity. Contention surrounds the ambiguity of the term 'suspicion of concussion'. Borne out of a lack of definitive definition and assessment, the term 'suspicion of concussion' was initially used to justify permanent removal from play under World rugby Guidelines. This is still the case at sub-elite levels. The current HIA documented above states that ‘suspicion’ can prompt a side-line assessment that if passed can lead to RTP. The criteria for ‘suspicion’ are listed below alongside the factors that should provoke permanent removal. (Table 2.7)(19) The lack of distinction between ‘possible’ or ‘definite’ confusion/behavioural changes may suggest that within the HIA system subjectivity/ambiguity still remains. As a result of this the HIA system within rugby union continues to be considered contentious and under review.

Table 2.7 Trigger criteria for HIA and permanent removal(19)

| HIA Trigger Criteria | Permanent Removal Criteria |
|---|---|
| • Head injury where diagnosis not apparent<br>• Possible behaviour changes<br>• Possible confusion<br>• Injury event witnessed with potential to result in a concussive injury<br>• Other symptoms or signs suggesting a suspected concussion | • Tonic posturing<br>• Convulsion<br>• Confirmed loss of consciousness<br>• Suspected loss of consciousness<br>• Balance disturbance / ataxia<br>• Player not orientated in time, place or person<br>• Clearly dazed – eyes vacant, blank expression, wandering eyes<br>• Definite confusion<br>• Definite behavioural changes |

### 2.6.10 Occulo-motor Assessment

Research into the assessment of impaired occulo-motor function has grown considerably in the last 5 years. It has been hypothesised that observed alterations in function are a result of shearing injuries of the frontal lobes and rostral to the midbrain, areas heavily involved with vision and eye movement.(294) As a result, evaluating such changes may provide measurable means of determining injury severity. Occulo-motor Impairments have been identified within vengeance, convergence, accommodation, vestibulo-occular reflex, photosensitivity, saccades and pursuit.(162)(Table 2.8) lists the types of neuro-ophthalmological abnormalities linked to mTBI and their associated pathways.

Table 2.8 Common eye movements, anatomical pathways involved and associated assessment tools.(295)

| Eye movement | Purpose | Anatomical pathway | Clinical tests to assess |
|---|---|---|---|
| Vergence | Coordinated movement of eyes apart or closer together to maintain fusion on objects | Cerebro-brainstem-cerebellar pathways. Not well understood | Most commonly assessed by measuring NPC |
| Vestibulo-ocular reflex | Stabilises images on the retina when the head is moved via compensatory eye movements | Semicircular canals signal to vestibular nuclei that excite the sixth nerve nucleus | Quick head thrusts whilst eyes fixate |
| Saccades | Rapidly shifting horizontal gaze | Intentionally generated in the frontal eye filed or reflexively generated from the parietal eye field, then contralateral paramedian pontine reticular formation stimulated, at times via the superior colliculus | Ask subject to fixate on peripheral target then central object like examiners nose |
| Pursuit | Follow slowly moving objects | Pathways from the temporo-parieto-occipital junction and frontal eye fields connect in pons and then innervate the cerebellum which then excites the nucleus of the sixth nerve | Track a slowly moving object |

Within occulo-motor assessment, attention has focused on the role of saccades, complex optical processes that occur autonomically when looking at a scene listed in table 2.9(294) Due to the anatomy of the human retina, the eye is not fixed on one point, but moves around creating a three-dimensional map of the image being observed.(296) Such 'saccadic' movements cannot be controlled voluntarily and occur extremely quickly and have been subdivided according to function.(294) Impaired saccadic function has been repeatedly linked(294) with concussive impairment and the means to assess this function has been achieved directly through video-oculography and indirectly using eye movement performance measures.(294)

Video-oculography commonly involves the use of goggles to quantatively record eye and head movements.(297) By attempting to focus on moving targets on a screen, eye movements associated with saccadic processes can be measured. This method has also been used to show how symptom recovery following mTBI correlates with normalization in occulo-motor function.(298) In addition, eye movement abnormalities have been found to correlate with MRI changes in mTBI patients.(249)(299) A closer appreciation of the specific eye movements involved in normal and post concussive test may also aid the issue referred to as 'sand-bagging', where athletes may intentionally limit their performance on baseline test to make passing post-concussion checks easier.(33) This and further research may provide the key evidence to support the use of occulo-motor assessment based on observable pathology.

Table 2.9 Examples of saccadic subtypes.(294)

| Saccade subtype | Description |
|---|---|
| Memory-guided saccades | Volitional saccades generated to the remembered location of a previously displayed visual target when the target is no longer visible. |
| Anti-saccades | Volitional saccades generated in the direction opposite to a visual target, which requires suppressing a saccade to the visual target. |
| Self-paced saccades | Volitional saccades made between two continuously present targets without verbal commands |
| Reflexive visually-guided saccades | Saccades involuntarily generated to an unexpected novel visual target. |

The primary drawback of video-occulography has been the practicality of its use, as the majority of its applications are laboratory based. In an attempt to negate this, portable devices have been trialled. Within a study of 12 boxers, Pearson *et al*.(300) used portable goggle saccadometry ringside. The study reported latencies within 7 minutes of a bout and demonstrated latency prolongation that resolved within days.(300) Considerable developments in technology have occurred since 2007 which have enabled video-occulography to advance. Two technology providers, EyeGuide and NeuroFlex are currently engaged in World Rugby backed research to evaluate further how oculomotor assessment could be used for rugby concussion management.(301) When launching the project, World Rugby chief medical officer Dr Éanna Falvey said;

> *"We believe that oculomotor screening examination in rugby has the potential to boost the identification and management of concussions by objectively identifying potential abnormalities in oculomotor function between a player's baseline and when removed for an HIA assessment, adding to the depth of identification methods available to the sport."*(301)

Until direct oculomotor assessment becomes a practical possibility, indirect occulo-motor assessment, based on the same functions as its direct counterpart has been used. Instead of recording eye motion through a lens however, it commonly relies on the assessment of occulo-motor function through the reading and recall of numbers. Due to the inclusion of the higher cortical processing required to verbalise the numbers, indirect assessment involves Brainstem, Cerebellum and Cortex in addition to the occulo-motor processes above.(32)

### 2.6.11 The King-Devick Test

The King-Devick Test (K-D) has emerged as the leading tool within indirect saccadic assessment.(31) The K-D Test was initially designed to assess reading ability(302) and it has been consistently used in an academic capacity ever since. In 2011, researchers published a study on the use of the K-D Test as a potential rapid side-line screening test for concussion in a cohort of boxers and mixed martial arts (MMA) fighters.(303) This sparked interest in its use within mTBI and over 200 articles including its use have been published since. The K-D Test requires the subject to read aloud a series of variably spaced numbers on a card as fast as possible whilst an observer confirms accuracy against an answer sheet (Figures 2.10 and 2.11) Three cards complete the test and become progressively harder to perform.(304) For children under 13, only the first two test cards are used. Each card provides a timed score and the number of errors noted and usually takes one to two minutes to complete.(294) The test is designed to incorporate a baseline test for comparison.

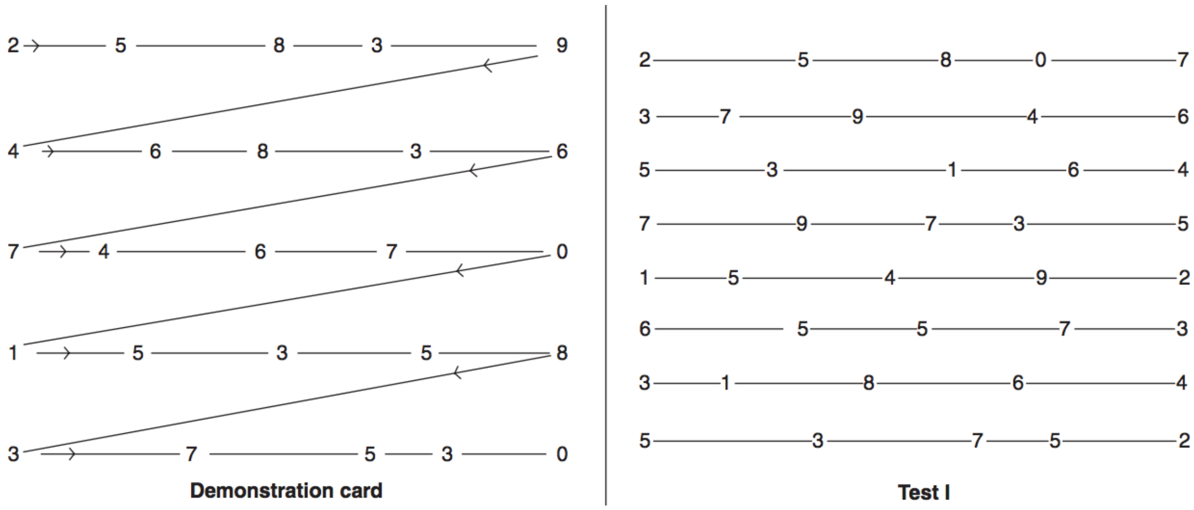


Figure 2.10 King-Devick Test Cards. Demo Card and Tests Card I

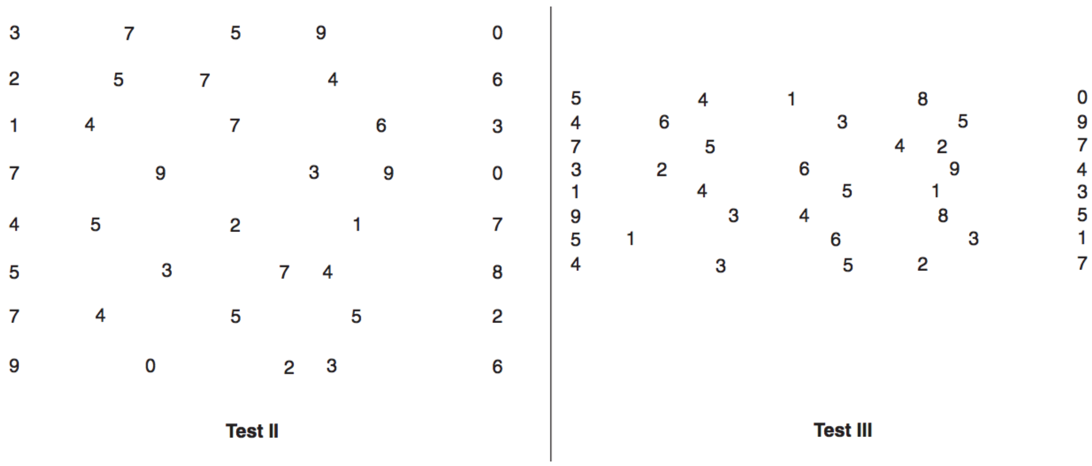


Figure 2.11 King-Devick Test Cards. Tests Card II &III

The first systematic review and meta-analysis of the use of the K-D Test within concussion was published by a research group from the University of Pennsylvania in 2015.(32) Galetta *et al.*(32) pooled 15 studies that had recorded baseline and follow up K-D Test scores for athletes in a range of sports. Over a thousand (1419) baseline scores were recorded for a range of athletes across levels and age groups. Over one hundred (112) concussions were diagnosed. Of these athletes an average worsening (increased time) of 4.8 s (95% CI: 3.7, 5.8; I2 = 0.0%; p = 0.58) of KD performance was noted. Non-concussed control group athletes showed an average improvement of 1.9 s (95% CI: -3.6 to -0.02; I2 = 0.0%; p = 0.99). Pooled analysis values for 'sensitivity' of the K-D Test for detecting concussion pitch-side were 86% (96/112 concussed athletes had any worsening of K-D Test time score from baseline; 95% CI: 78%, 92%); 'specificity' was 90% (18 1/2 02 non-concussed control athletes had no worsening of K-D from baseline, 95% CI: 85%, 93%). The data showed participant's speed of completion was better with increased age as other studies had shown. The meta-analysis also revealed high test-re-test reliability of the K-D Test highlighting that successful application did not involve experienced supervision. The study concluded that the K-D Test adds the critical dimension of vision to sports related concussion assessment.(32)

The K-D Test has also been evaluated against other commonly used concussion screens. Alsalaheen *et al.*(305) compared K-D baseline ability of 157 high school American Football players against the Balance Error Score System (BESS) and Limits of Stability Test (LoS).(305) The study found no relationship between all three tests for healthy individuals. This is hypothesised to demonstrate the unique cognitive and physiological pathways each test measures and, therefore, the necessity to include occulo-motor testing in the form of the K-D when screening pitch-side.(305) This study also added to the growing body of normative reference values for the K-D Test.(33)(306)

The findings of this study were supported more recently by a review of the diagnostic accuracy and reliability of side-line concussion evaluation tools by Harmon *et al*.(307) This took the form of a prospective, case-controlled study of 81 US college athletes who completed baseline tests including Post-Concussion Symptom Scale, Standardised Assessment of Concussion (SAC), modified Balance Error Scoring System (m-BESS), K-D Test and EYE- SYNC Smooth Pursuits.(307) Data was collected from 41 concussed athletes and 41 match control subjects. The authors report that among the objective tests assessed in this study, the K-D Test had the highest reliability (0.71), sensitivity (85%), specificity (76%) and AAUC (0.78) (Adjusted Area Under the Curve, a combination of sensitivity and specificity used to define likelihood of having a condition). Despite these findings, the authors conclude that the figures established for the K-D Test differ from those previously published, a factor yet to be accounted for.(307)

Due to the complexity of the saccadic and cognitive processes involved in the K-D Test, the lack of direct understanding of its mechanisms was initially cited as a criticism of its use. To negate this, further investigation was required to compare normal subjects' saccadic performance with those following head injuries. To this end, Rizzo *et al.*(33) studied the specific eye movements occurring during the conduction of the K-D Test for 12 healthy participants. Through the linking of video based infra-red occulography with the K-D Test, Rizzo *et al.*(33) found that on average 145 saccades occurred during test conduction.(33) With this study design as a framework, assessing the differences in cognitive and autonomic eye movement between healthy subjects and those following head injury should be possible. The ongoing developments in direct occulography discussed above (section 2.6.4) should also allow the efficacy of more simple tools like the K-D to be established through comparison.

The most recent systematic review and meta-analysis to include the K-D Test for sport related concussion was published in 2021.(308) After 809 studies were identified, eight met inclusion criteria and all included K-D Test use. Despite demonstrating similar pooled sensitivity and specificity findings to those previously published, the authors found that evidence levels and heterogeneity across the studies differ echoing the conclusions of Harmon *et al.*(307) As such, the authors suggest that the K-D Test may be of value to a pitch-side assessor but should be used alongside other subjective reporting tools such as the SCAT test.(308)

Despite the high rate of head injuries observed within both codes of rugby, minimal studies incorporating the K-D Test have occurred. The research conducted has so far has largely come from New Zealand through the work of Doug King and associates. Through head injury investigation incorporating youth and adult cohorts in rugby League and union, King *et al.*(304)(309) have made the most pressing case for K-D Tests inclusion in governing body protocols. Using amateur participants in both codes, King *et al.*(8) sought to evaluate the applicability of the K-D Test as a pitch side tool and see if routine follow up might highlight otherwise undetected impairments.(8) A squad of players from both codes was followed through a competitive season. A total of 52 (8 witnessed; 44 un-witnessed) concussive events were identified over the duration of the study resulting in a cumulative concussion injury incidence of 44 (95% CI: 32 to 56) per 1000 match participation hours. Poorer K-D performances also correlated with reduced SAC test scores.(8) Interestingly the researchers found that an impaired score on K-D testing, indicating a possible injury, was six-times more likely to go un-witnessed than observed and diagnosed by medical staff. This may have implications for the study of the long-term consequences of seemingly sub-concussive blows. Although not evaluated fully, King *et al.* also observed medical staff incorporating repeated K-D testing as part of a recovery process. By using it as a tool to predict cognitive recovery, specific guidance on when to commence GRTP protocols occurred. As a result King *et al*.(8) suggest that the K-D Test is a practical tool that should be incorporated into pitch side assessment alongside balance and recall tests and can be used as an aid to monitor recovery.(8)

Most recently, King *et al*.(310) continued to expanded their K-D based work through an investigation of its use in amateur New Zealand women's rugby.(310) Competitive players from one team (n=69) underwent two seasons of K-D baseline concussion assessments. Players removed from play due to the reporting of recognised signs of concussion, or suspected to have received a concussion by side line medics, were screened with the K-D Test after a 15 min rest period (n=10). The K-D post-injury (concussion) side-line test scores were significantly slower than the established baselines. This led to excellent reliability of the K-D Test for baseline (ICC: 0.84 to 0.89), post-injury (concussion) side-line assessment (ICC: 0.82 to 0.97) and post-season evaluation (ICC: 0.79 to 0.83)(ICC= intra-class correlation coefficient). As women's rugby has become one of the fastest growing sports worldwide and a focus for World Rugby(311), further women specific head injury research is warranted.

As with all published K-D based investigations, the researchers note that the test was employed as a screening tool, not a diagnostic measure of concussion.(310) This mirrors the tests designed role as a constituent part of a wider neurological assessment,(312) rather than a stand-alone tool. This may account for the 2016-17 RFU backed K-D trial findings which suggest that the K-D Test is unsuitable as a stand-alone alternative to the current multi-model HIA.(36)(see section 2.6.9) It is in its intended multi-model capacity that the K-D Test is to be used within the development of a comprehensive acute concussion assessment and passport for Irish adolescent rugby players.(313) The World Rugby backed researchers aim to investigate how a variety of diagnostic tools interact with each other as participants recover from concussion. The K-D Test will run alongside the SCAT3 tool (see section 2.6.7) BESS, ICS Impulse Goggles, (see section 2.6.5) the CogState Brief Battery, (see section 2.6.8) and the Buffalo Concussion Treadmill test, a long-term symptom assessment.(314) Blood tests, neck strength and activity monitoring are also planned to take place for Dublin based senior school players. Following the study, the researchers aim to determine the logistics of recording an individual's concussion history on a virtual 'Concussion Passport' that would remain with the individual throughout their sporting career.(313) By using the K-D test as part of a multi-model battery of assessments in this manor, each neurophysiological aspect of concussion symptom observation can be accounted for. The effects of 'Sand bagging', referring to purposefully underperfroming on baseline recording to reduce the threshold for post injury assessment discussed in section 3.5, can also be diluted.

Such research within rugby and the wider sporting world has opened up further avenues for K-D Test use. As discussed in section 2.6.4, once goggle-based technologies have been validated, comparing them with more accessible, indirect occulography tools like the K-D Test, can occur, which may add rigor to indirect oculomotor concussion assessment, even if not gold standard. It would then be possible for a pitch-side practical tool such as the K-D Test to be widely used. This would leave only licencing limitations as the barrier to wide-scale use. In light of the practicality, specificity, sensitivity and previous use within rugby discussed above, the K-D test was chosen for exploratory use within Study One of this thesis.

## 2.7 Stakeholder Role, Knowledge and Attitudes

The responsibility of injury prevention and management within all sporting environments is shared between key actors. Community rugby is no exception. Each stakeholder may play a different role, but their collective decision making and actions shape health outcomes.(315) The key stakeholders within youth community rugby are coaches, parents, officials, medical staff and arguably most importantly, the players. The sections below discuss research of the knowledge and attitude of parents, commonly also Emergency First Aider's (EFA's) and players. Enhancing the understanding of the knowledge and attitudes of these key stakeholders is a necessity in the development of targeted risk reduction strategies. As such it is a core aim of this thesis.

### 2.7.1 Parents

### 2.7.2 Knowledge

Literary consensus suggests that parental concussion knowledge, including the awareness of symptoms, post concussive care, and RTP guidelines, is variable. (316-320) Stevens *et al.*(317) present a striking example. From a convenience sample of 105 children diagnosed with concussion attending a US paediatric emergency department, 62.9% experienced concussive symptoms. Despite this, 69.5% of their parents initially stated that they were asymptomatic.(317) Although these finding are not specifically sporting related, Kay *et al.*(321) surveyed 234 youth sports parents and also found only moderate concussion related knowledge. Parents failed to identify defined concussion symptoms and included symptoms not specific to concussion when questioned.(321) In contrast, Lin *et al*.(316) reports high parental concussion knowledge from a survey of 214 US based parents who accompanied a child to one of five paediatric trauma centres.(316). Although the study asked parents questions surrounding sports related concussion, musculoskeletal or mTBI injuries were the only mechanism of injury inclusion criteria and no information as to how the injury occurred was reported. The results may also be influenced through subject inclusion, as parents' who choose to seek primary care for their child, over those that may not, may reflect greater care and/or understanding of concussion.

The Lin *et al.*(316) investigation aligns with that of Nanos *et al.*(322), when exploring differences in male and female parental concussion knowledge. Nanos *et al*. (322), who included parents in an exploration of youth sport-related concussion knowledge, similarly found no difference in concussion knowledge between 34 male and 98 female parents despite a small and disproportionate sample split.(322), Both studies also report an association between broader parental education levels and higher concussion knowledge.(316)(322) Within rugby union investigation, Sullivan *et al.*(319) studied 200 New Zealand youth community rugby parents reporting that most (83%) felt able to recognise a potential concussive injury in their child, with nearly all (96%) being aware of the consequences of playing through a concussion.(319) The study found that after responses were recoded and mapped using a consensus approach, onto a framework based on the Sport Concussion Assessment Tool 5 (SCAT5), 623 of 658 items (95%) had been successfully classified by parents, demonstrating a high level of concussion assessment knowledge.(319) Despite this only half (51% 99-196) of the parents stated they were aware of the existing RTP guidelines.(319)

As described above, parental concussion knowledge research has been broad and revealed mixed levels of parental understanding. Findings have varied across nations and sports which may reflect the impact of variable concussion awareness and education initiatives. Furthermore, to date, research has not fully identified whether parental concussion knowledge translates into practical health care choices, or influences parent-child communication regarding symptom reporting, which may in part, have led to what has been described as a startling lack of focus on the parents of paediatric athletes by sport's governing bodies.(316)(323)(324) More recently, sport's governing bodies have begun attempts to target parents for concussion education.(18)(316) Developments in this area, against a backdrop of increasing sports related concussion awareness, may improve parent knowledge and effect parental decision making. Continued research in this field is, therefore, necessary to ensure education programmes are validated and effective.

### 2.7.3 Attitudes

It is widely established that regardless of a parent's knowledge of concussion, their attitudes towards concussion management heavily influences their own, and their child's, care seeking behaviour.(321)(325)(326) If attitudes are negative or parents are hesitant towards disclosure, they may be less inclined to report their child's injury, greatly decreasing their safety.(321)

The understanding of how attitudes effect choices and behaviour has been a consistent research topic for social psychologists since the disciplines birth in the early 20$^{th}$ century. The Theory of Planned Behaviour (TPB).(327) Developed by preeminent social psychologist Icek Ajzen in 1985, TPB has become one of the most prominent predictive behaviour frameworks. TPB is based on the construct of perceived behavioural control. If an individual perceives a behaviour to be easy to perform, it is deemed high in perceived behavioural control and the person is considered more like to perform it. In contrast, if a behaviour is deemed hard to perform, it is less likely to be carried out. Within a parental concussion management context, if a parent does not feel they have high behavioural control with regards to education, assessment and management of a child's injury, an intervention is likely to occur. Having an appreciation of parental concussion attitudes is, therefore, imperative to successful injury prevention interventions. Designed specifically for health and wellbeing attitudes, the Health Belief Model (HBM) developed in the 1950's by US social psychologists Janz and Becker, has also been consistently used to interpret the potential drivers to such choices.(328) The HBM is based on six constructs that influence a person's decision about whether to take action. These include perceived susceptibility, perceived severity, benefits, barriers, cues to action and self-efficacy.

Despite this, little exploratory research using such frameworks has been conducted on key parental attitudes to childhood head injuries. Of the 12 studies to specifically describe parental concussion attitudes, common themes can however be derived. Within the survey assessment of 234 sports parents, Kay *et al.*(276) used a previously validated survey (276) and reported largely positive attitudes towards concussion from sports parents, despite identifying only moderate understanding.(321) Although not explicitly defined by the study, what is deemed a 'positive attitude' appears to be in-line with general concussion best practice guidance.

A further study by Lin *et al.*(316) developed a Concussion Attitude Index (CAI), similar to that previously employed by Rosenbaum and Arnett,(329) discussed in sections 2.7.2.1 and 2.7.3.The study reports mostly positive parental attitudes towards concussion with a mean score of 63.1 on a scale from 15-75.(316) In contrast to studies suggesting no significant difference in gender concussion knowledge(316)(322), Lin *et al.*(316) observed significant differences in concussion attitudes between the sexes. Women scored higher (63.8) than men (61.2).(316) Combined gender concussion attitudes also matched the trend seen with concussion knowledge, increasingly positive scores in line with rising household income and education level.(316)

The investigation by Lin *et al*.(316) also found no association between either concussion knowledge or attitudes with parents previous experiences of concussion, either personally or with their child.(316) This finding was contrary to the authors expectations that previous experience would increase perceived susceptibility and knowledge, As might be predicted by the HBM,(328) and a commonly purported outcome.(330) This longstanding theory was supported by Kroshus *et al.*(325) who found a greater perceived likelihood of a future concussion by parents of previously concussed youths.(325) An explanation of these findings may be similar to drivers of player attitudes, driven by the perception of risk versus reward.(331) If a parent believes that following their child's reporting of a minor concussion they will be unnecessarily kept out of play, leading to reduced competitive opportunities, prior parental concussion knowledge could negatively influence parent and child's reporting likelihood.(321)(325) In contrast, if greater awareness of the effects of concussion are experienced by a parent through either their or their child's injury, they may become more aware of its effects and heighten the importance they place on symptom reporting.(325)

Kroshus *et al.*(39), an extensively published author within psycho-social aspects of concussion management, believes the primary influence between a parent adopting a positive, safer attitude, or more negative, risk taking attitude towards concussion, lies in the extent of their drive for sporting achievement.(39)(325)(331) This may be where differing sociological forces between mothers and fathers leads to contrasting concussion attitudes and resultant behaviours. Brussoni *et al.*(332) identifies a father's perceptions of their own ‘masculine identities’ as having important implications for how they engage with young children.(332)(333) This has been cited to explain why male caregivers appear to have a different approach towards risk taking and safety than female caregiver, as they may assign greater value to the developmental aspects of sports, even at the risk of minor injury.(325)(332) Whether the impact of sociological gender norms, in combination with cultural and environmental factors, leads men to have a heightened sense of the rewards of sports such as rugby, in spite of their risk awareness, remains undefined. Furthermore, whether such attitudes overtly or subconsciously apply pressure or influence a child’s decision making, remains to be established. Kroshus *et al.*(39) takes the concept of risk/reward and pressure a step further, stating that if an athlete feels that their parents are highly invested in their sporting success, regardless of their own attitudes towards concussion, they may perceive that their parents would be supportive of their continued play whilst symptomatic.(325) As a result, the more pressure that is placed on a child, the less likely they are to report concussion.(325) When combined with Kroshus *et al.*(334) finding that the most socio-economically disadvantaged parents report the greatest concussion concern for their children,(334) weather a drive for their child’s sporting success and higher economic status, factors typically associated with rugby union in the UK, further reduces parental concern is an intriguing factor yet to be explored within Rugby concussion research.

Just as heightened parental pressure has been suggested to strongly influence young sportspeople’s decision making,(331)(335) it has also be shown to impact medical practitioners evaluations. Within a study of attention deficit hyperactivity disorder

(ADHD) Rafalovich(17) found that practitioners become more flexible in their implementation of diagnostic and treatment protocols when faced with patient/parent resistance, itself fuelled by broader public debate over the condition.(17) In light of the similar degree of medical uncertainly and public debate surrounding concussion, it is plausible that this may also occur in youth sports medicine environments.(336)

As the behaviour predicting models described above suggest, the small but growing body of research on parental/caregiver's concussion engagement reports that parent's knowledge, attitudes and experiences interact to influence likely behaviour. How this fully translates to real world concussion safety within rugby is yet to be established. As parents/caregivers also commonly play key roles within youth community rugby such as coaching or first aid provision, further investigation is essential to define these interactions and highlight areas for targeted governing body intervention.

### 2.7.4 Perceived Role

It is widely reported within the literature that parents/caregivers play an instrumental role in forming the safety attitudes and behaviours of young sports players. (321)(325)(337) A parents role has been cited as the greatest influence on child care–seeking behaviour.(326) In addition to attitude shaping, parents have been cited to influence three key areas within sport; concussion prevention, identification and treatment.(321) Encouragingly, parents have demonstrated a desire to take on an active role in communicating about concussion with young athletes, however barriers to successful interactions have been observed.(338) Despite a growing body of evidence surrounding the understanding of parental concussion knowledge and attitudes(1)(315)(316)(338)(339), far less investigation has been dedicated to what parents perceive their role to be within youth concussion management. Of the studies published, all are limited by small participant numbers and variations in methodology.(315)(338) As part of a wider evaluation of the US Centre for Disease Control (CDC) 'HEADS UP' concussion education and awareness campaign, Sarmiento *et al.*(338) conducted a qualitative study based on a Grounded Theory methodology. The parents of 16 players of various sports aged between 12-18 participated in six focus group sessions.(338) After reporting their own perceptions of concussion, parents were asked to discuss aspects of concussion specific parent-child communication. Although reportedly comfortable in doing so, engagement in a concussion communication by parents varied. Commonly, parents cited their perceived degree of influence as limited and that they have little preventative role. Parents appeared reliant on coaches to educate players around concussion and felt personally under educated as to their role within concussion management.(338) Despite the limited sample size of this study preventing broad generalisation, poor parental self-efficacy within concussion management has been echoed by other studies.

In an exploration of Caregivers of Young Athletes (CYA) perceptions of concussion, Patel and Trowbridge(340) highlight similarly low levels of caregiver educating confidence.(340) Using the HBM discussed above, 20 key informants (coaches, concussion experts etc.) and 30 CYAs, undertook in-depth interviews with researchers lasting 30-45 minutes. The researchers report that despite receiving sports related concussion education, CYA's consistently stated a lack of understanding and self-efficacy in concussion educating. Despite this, the authors suggest using the HBM as a vehicle for caregiver concussion education with a view to improved player support.(340) The HBM,(328) Theory of Planned Behaviour (TPB)(327) and Intervention Mapping (IM) (341) discussed above, have been proposed as suitable structures from which to develop concussion prevention programmes. As described above, the HBM is based on six main constructs, it is however the last construct of self-efficacy, that Patel and Trowbridge(340) cite as one of the key barriers to greater parental engagement in concussion management. Whether male caregivers demonstrate greater self-efficacy within a concussion communication role remains to be evaluated as this study included mostly women (27/30).

As part of a wider investigation of community rugby union stakeholder attitudes, Clacy *et al.*(1) interviewed 18 parents and identified their perceived roles and responsibilities within concussion management (Table 2.10) Clacy *et al.*(1) report that 61% of parents indicated they are involved in concussion prevention, 94% felt they were able to accurately identify concussion and 33% felt they had a role in concussion treatment.(1) Despite the authors conclusions that parents should play an active role in communicating rugby related concussion safety to their child, to date, no targeted education to promote parent-child communication has been developed by rugby governing bodies.

Table 2.10 The most commonly reported perceived parental concussion roles/responsibilities from Clacy *et al.*(1)

| | |
|---|---|
| Seeking medical help and advice | Removing their child from play |
| Providing headgear | Ensuring their child is being taught the correct tackling technique |
| Facilitating fitness and skill development | Monitoring children's health symptoms |
| Ensuring their child receives appropriate medical attention | |

### 2.7.5 Players

### 2.7.6 Player Knowledge

Over the last decade several studies have sought to identify the degree of youth concussion knowledge across many sports with common themes identified. A frequent finding in the literature has been the lack of concussion symptom recognition by players.(342-344) When assessing 334 high school American Football players, Cournoyer and Tripp(344) concluded that players did not have appropriate knowledge of the symptoms and consequences of concussion.(344) Commonly players identified headaches (97%), dizziness (93%) and confusion (90%) as symptoms, but were less successful in identifying nausea or vomiting (53%) neck pain (52%), grogginess (52%), and behavioural changes (39%). More worryingly only 63% of players report coma, 69% brain haemorrhage and 64% death, as potential concussion outcomes.(344) Receiving parental given concussion education was reported by 54% of players, whilst 60% state receiving formal education either in class or online. The researchers found no association between reported education level and a better knowledge of concussion symptoms and consequences.(344)

Limited youth player concussion symptom knowledge was also recorded by Fedor and Gunstad(342) who assessed 382 college athletes(342) and identified that students showed an incomplete understanding of concussion symptoms, particularly emotional changes.(342) However, the athletes concussion symptom knowledge was comparatively greater than 230 non-athletes surveyed as a control, supporting the hypothesis that despite young players being commonly unaware of the more severe and behavioural aspects of concussion, sporting engagement does increase concussion knowledge. Miyashita *et* *al.*(343) also found through the assessment of personal injury histories (n=454), the majority of young athletes sampled failed to realise the severity and seriousness of concussion. Typifying this was the number of athletes who reported having their 'bell rung' (n=297), a colloquial term for having sustained a concussion, compared with athletes who report having sustained 'concussion' (n=172).(343) The ability of young sports people to adequately define concussion and appreciate all its symptoms is unsurprising considering the challenge it has presented to expert consensus groups.(116)

A commonly cited limitation of the majority of surveys developed to assess concussion knowledge and attitudes is their lack of expose to psychometric analysis.(345) The Rosenbaum Concussion Knowledge and Attitudes Survey – Student Version (RoCKAS-ST) is a prominent exception having undergone reliability analysis by both the authors(329) and Chapman *et al.*(345) The RoCKAS-ST was initially developed through the assessment of 529 American high-school athletes knowledge and attitudes towards concussion.(329) The survey comprises a series of true or false and Likert Scale questions, which when analysed, form the Concussion Knowledge Index (CKI) and Concussion Attitudes Index (CAI). Rosenbaum and Arnett's initial 2010 RoCKAS-ST analysis demonstrated fair to satisfactory test-retest reliability (knowledge items, $r = .67$; attitude items, $r = .79$), attitude item factor analysis presented a four factor solution (eigen values 1.07-3.35) with adequate internal consistency (Cronbach alpha range = .59-.72), and knowledge item cluster analysis presented a three-cluster solution distributed according to question difficulty.(329) Despite moderate reliability and consistency, the rigour exposed to the ROCKAS-ST has led to its inclusion in several subsequent concussion knowledge and attitude measures.(316)(346)(347) The RoCKAS-ST is discussed further in section 2.7.3.

Rugby union player concussion knowledge research has been limited to date, especially within youth populations. The earliest published study, conducted by Sye *et al.*(348), surveyed 477 New Zealand high school male rugby players. Despite almost all players being aware of the term concussion, only 61% felt they understood the meaning of the term.(348) The researchers report that the group demonstrated a reasonable knowledge of common concussion symptoms although 25% indicated, “being knocked out cold”, as the best descriptor of concussion.(348) In addition, although 77% of players stated that someone should not RTP if still experiencing symptoms, 27% of players agreed that a player with a suspected concussion should play in an important game such as a final.(348) This pioneering research helped to direct education strategies, including the New Zealand rugbySmart(349) programme discussed in section 2.8.1. It should, however, be noted that surveys of this nature are particularly time sensitive. Whether similar results would be seen following the rise in public awareness and education that has occurred in the subsequent years since its publication, remains unknown. It is, therefore, imperative that player knowledge and attitude investigation is frequent, consistent and used to validate novel prevention interventions.

The study of under 20 Irish rugby players (n=133) by Baker *et al.*(43) found a similar trend in symptom recognition to other sports, with headache and memory difficulties most cited, and emotional sequale least reported (if at all). Overall, a mean of 2.6 (SD 1.6) symptoms were listed by players.(43) The study found that nearly half of the players surveyed (48%) reported a history of sustaining at least one concussion, with 70% stating that concussion was as serious as other injuries. The majority (85%) reported that they would inform someone if they thought they had suffered a concussion and 83% would report if they thought a teammate had experienced the same.(43) Despite these positive findings, a large proportion of players felt that headgear (45%), and gum shields (40%), were protective against concussion.(43) This study, in accordance with Sye *et al.*(348) and Hollis *et al.*(44) found the weakest aspect of youth rugby players concussion knowledge was within the understanding of RTP guidelines. Whether poor adherence to guidelines observed and reported in rugby is driven by a lack of knowledge, attitude, or a combination of both, remains to be defined.(44)

The most recent UK investigation of youth rugby player concussion knowledge and attitudes was conducted at three state schools and three rugby clubs in the South of England by Kearney and See.(350) Surveys were completed by 238 male and 17 female players aged between 11 -17 years. Similarly to previous studies, the players surveyed demonstrated poor knowledge of the symptoms of concussion.(350) Also consistent with previous adult community rugby research showing poor adherence to RTP guidelines(10), only 12% of those players whom reported sustaining a concussion adhered to recommended RTP guidance.(350) Although limited in female numbers, this is the first youth rugby union head injury study to include male and female participants. Due to anthropometric differences,(351) greater concussion risk(170) and the rise in women's rugby participation, greater female focused concussion research is required.

### 2.7.7 Player Attitudes

In addition to the noted concussion knowledge limitations of sports people, reported concussion attitudes vary across a growing literature base. Understanding the problem, in this case a lack of appreciation of player attitude towards concussion, is a vital component of developing suitably targeted education and behaviour change interventions, as described within all risk reduction frameworks. Gaining a greater insight of youth player attitudes towards concussion is a key aim of this thesis, as it will inform how concussion education can be optimised to promote player safety within rugby.

Within attitude assessment, the primary focus of research has been on how attitudes influence potential head injury disclosure. Several studies have drawn the assumption, without distinct evidence, that poor concussion knowledge leads to a higher likelihood of under-reporting.(342) If a player is unaware that the symptoms they may be experiencing are from concussion, this would seem a plausible explanation for a lack of reporting. However, Anderson *et al.*(352) suggests that a link between concussion knowledge and attitude may be more complex. Through the questionnaire assessment of high school American Football players, Anderson's research group found no association between concussion knowledge and attitude scores.(352) This led to the conclusion that despite having sufficient knowledge, many athletes had negative attitudes towards reporting and/or abstaining from play following head injury.(352) These findings suggest that despite the growing implementation of concussion education initiatives/programmes, there has been no concurrent improvement in attitudes.

This finding was supported by Conway *et al.*(353) who similarly found greater concussion knowledge did not reduce the number of reasons National Collegiate Athletic Association athletes suggested as drivers for non-disclosure.(353) The cross sectional study concluded that the majority of the 156 athletes assessed clearly understood why fellow athletes might choose not to disclose concussions, even when they were aware of the potential consequences and risks.(353) Within adult rugby this characteristic also seems apparent. O'Connell and Molloy(354) found a high likelihood that players engage knowingly in unsafe behaviour despite high concussion knowledge. Although only five Irish rugby teams were surveyed, the authors also note no difference in such attitudes between genders and competitive levels.(354)

A potential explanation for these findings has been presented by Chinn *et al*.(355) Through the study of 986 college student athletes across six sports, the researchers found that concussion knowledge was weakly associated with concussion education, but increased knowledge did not lead to greater reporting.(355) Chinn and colleagues initially employed the ROCKAS-ST survey described above to quantify concussion knowledge and attitudes, followed by qualitative interviews conducted with participants selected through purposive sampling. Students were approached that noted 1) A reported history of concussion, 2) Indicated a lack of concussion reporting for concussions they had sustained, 3) Ranked "I was into the practice/game and didn't realize I had a concussion" as primary reason for not self-reporting concussion, 4) indicated concussion education was received from an athletic trainer and/or coach. From 18 participants that met these criteria, nine agreed to interviews. Despite almost three quarters of all participants receiving concussion education, mostly in lecture form, it did not positively influence the likely reporting behaviour of those interviewed. The rationale presented for this outcome was twofold. Firstly, the students interviewed report not be cognisant of possible concussion during the stress of sporting competition due to physiological responses. The participants cite ‘being in the zone’ and ‘Adrenaline’ as possible reasons for non-disclosure.(355) Secondly, those interviewed reported mitigating attitudes such as a sense of commitment to the team, overly positive self-evaluation and denial.(355) Whether concussion under reporting is a conscious choice, as indicated by Conway *et al.*(353), or influenced by stress/environment as suggested by Chinn *et al.*(355), the drivers behind concussion reporting remain poorly defined.

The impact of experiencing a concussion on the likelihood of further disclosure behaviour has also been studied. An investigation of the association between self-reported concussion history, concussion knowledge and disclosure behaviour by Register-Malik *et al.*,(42) found a greater number of previous concussions led to a greater likelihood of negative disclosure.(42) Through the cross-sectional investigation of 167 high school athletes, Register-malik *et al*.(42) concluded that the observed phenomena may be a result of several beliefs. Firstly, that if no perceived disabilities result from an injury deemed concussion, an individual may feel that there is no benefit to reporting a subsequent injury.(42) Secondly, if athletes have negative attitudes towards removal from play and the manner in which suspected concussion is managed, injury disclosure may again be withheld.(42) Lastly, Register-malik *et al*.(42) cited the influence of environmental norms as a key driver of disclosure attitudes. Register-mailk *et al.*(42) concludes that concussion attitude, and personal experience of concussion, are the main factors that drive concussion disclosure, rather than player knowledge.(42) This is supported by Anderson *et al.*(352)

whom also de-values concussion knowledge in favour of attitude being the main determinant of concussion disclosure.(352) An example of this in action is presented by Miyashita *et al.*(343) who studied perceptions of concussion of 454 high school athletes and found that 50% of participants felt that the importance of the event/game should dictate RTP.(343)

The majority of concussion attitude investigation has centred on male participant beliefs. To address this discrepancy, Kroshus *et al.*(356) conducted a comparison survey between male (n=154) and female (n=174) US college athletes regarding their reporting intention and behaviour. The study found that female athletes were more likely than male athletes to intend to report symptoms of a future concussion.(356) Reporting intention was also greater amongst athletes who conformed less strongly to traditionally masculine norms of self-reliance and winning. As has been identified with other research,(357)(358) this outcome did not however infer that males are more likely to conform to masculine norms, as both sexes demonstrated similar levels of association with winning and self-reliance.(333) Kroshus *et al*.(356) asserts that the key influence toward injury disclosure at the time of injury may come from the value placed on winning, whereas subsequent deliberative reflections about reporting intention that occur later, might reveal gender differences.(356) Despite observing a greater likelihood for females to report a concussion after educational intervention within a younger, high school cohort, Miyashita *et al.*(359) also found no differences between sexes regarding rationale for not reporting a concussion.

In order to clarify the varied factors that influence concussion under-reporting in youth sports performers documented above, Pennock *et al.*(360) included 26 studies within a 2020 systematic review.(360) Of the 26 studies to meet inclusion criteria, 21 were cross sectional in design, three were cohort studies and two were qualitative studies. Sample sizes ranged from 31 to 778 participants with a mean of 337. Just over half of the studies included athletes from a range of sports with 12 studies being focused on a single sport, three of which from rugby union. The authors conclude that despite differences in study designs, under-reporting was evident in all 26 studies. Just over half (14) of the studies described athletes' reasons for under reporting. Figure 2.12 depicts the reported barriers for SRC disclosure using conceptual mapping presented by Pennock *et al.*(360) The systematic review supports evidence described above that youth female athletes are more likely to report concussion symptoms compared to males, despite no differences in their reasons for potential under-disclosure. No definitive difference in reporting intent between age groups was also found due to conflicting evidence. Both of these findings have implications for concussion education


Figure 2.12 Barriers for SRC disclosure from Pennock *et al.*(360)

The systematic review by Pennock *et al.*(360) forms the most comprehensive assessment of youth sports attitudes that influence the key safety factors surrounding concussion disclosure to date. In addition to detailing the most frequently sited reasons for non-disclosure, the authors primary finding is that education and prior concussion knowledge do not appear to be effective deterrents to under reporting. These findings have distinct relevance for stakeholders and governing bodies engaged with designing appropriate risk reduction strategies. As is discussed in more depth below, Pennock *et al*.(360) highlight that the consideration of broader social and cultural behaviour drivers is key to understanding and, in turn, influencing athletes' decisions.

Despite the comprehensive nature of this review's findings, it does not fully bridge the inherent gap between player reported intention and their actual behaviour. Within sports concussion research, the current lack of validated, practical assessment tools to identify concussions, reported or otherwise, hampers this study design. When such assessment tools are available, determining the extent to which intended and actual behaviour is associated will be possible. This will then help direct and validate future attitude investigation methodologies.

Within rugby, as with other sports, concussion attitude appreciation has been largely focused on adult level participants.(354)(361) During the 2015 season, Martin *et al.*(362) conducted the largest knowledge and attitude investigation of adult community level rugby players in Canada. The survey-based investigation included 10 questions on attitudes towards concussion that were completed by 171 male and 113 female players.(362) Figure 2.13 below details the findings.

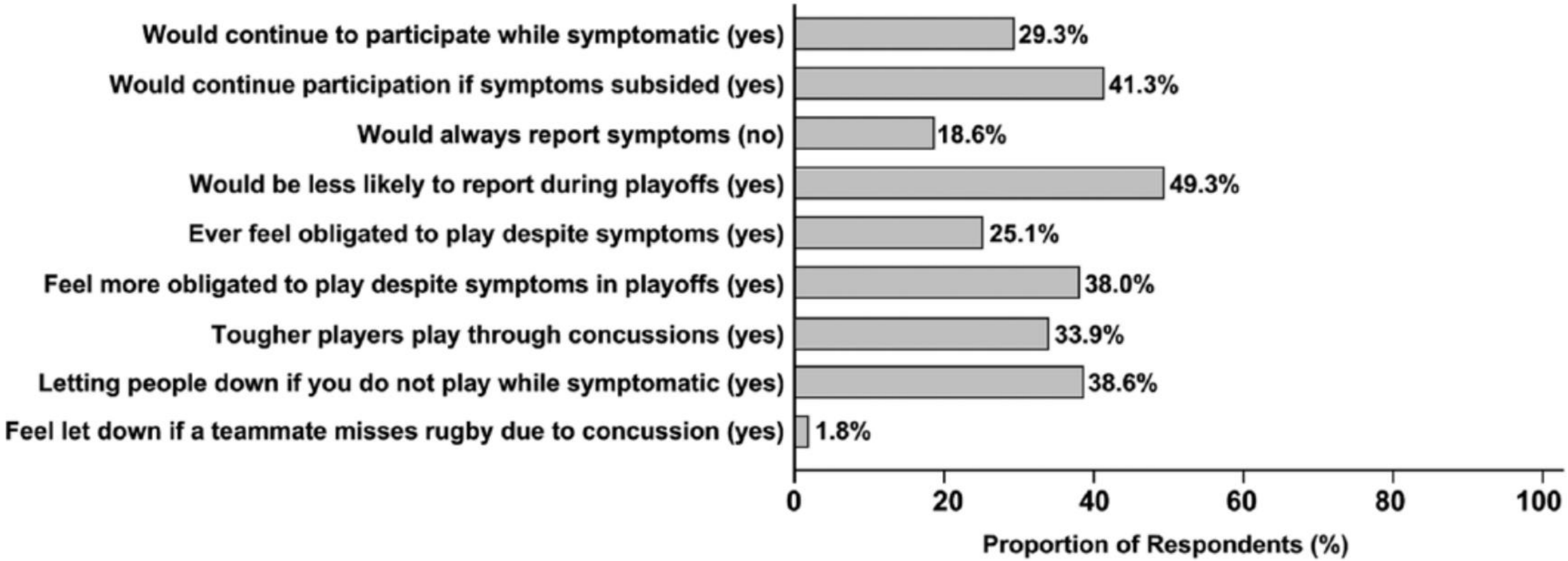


Figure 2.13 Participant responses to questions pertaining to attitudes and influences regarding concussion risk and management. From Martin *et al.*(362)

The results present a concerning degree of participant willingness to continue play whilst experiencing symptoms. This is compounded further by what the authors describe as, “a near-ubiquitous appreciation of the dangers”.(362) The authors hypothesise that the knowledge-attitude discord displayed may stem from an underlying culture of being commended for “playing injured” or a desire to appear “tough.”(362) Such cultural drivers impact on concussion attitudes within rugby have not been fully established. If they do present an influence in this regard, cultural shifts over time render the findings of research particularly time dependant. This factor requires appreciation when comparing results or attempting to predict future behaviours. In addition to the unavoidably dated study findings, this survey, and those of which it was based, lack formal validation. This is a consistent limitation of published concussion knowledge and attitude investigation.

To date, youth level rugby player concussion attitude evaluation has been scarce. The 2015 study conducted by Delahunty *et al.*(363) of 304 12-18-year-old participants concussion attitudes in Irish schools, forms the first specific review within this cohort. This anonymous cross-sectional survey found that despite broad awareness of the potential seriousness of concussion, 72.5% of respondents stated they would play an important match if still recovering. Of the 59 players who reported having a diagnosed concussion, 83.1% (n=49) reported that they would play an important match even if they believed they were concussed, compared with 70.2% (172/245) of those who had never experienced a concussion. This supports the rationale of Register-Malik *et al.*(42) discussed above, that prior experience and, therefore, knowledge of concussion, reduces rather than promotes reporting intention. Perhaps the most concerning finding from Delahunty *et al*.(363) investigation is that only 29.8% of players surveyed indicated that they would self-declare concussion symptoms. This supports findings from adult cohorts within rugby discussed above, and the wider sporting world, of persistent concussion symptom under-reporting.

Although ground breaking at the time, Delahunty and colleague's investigation findings are now somewhat dated as concussion awareness, management and education have developed. In 2017 Kearney and See(350) conducted the first UK community level youth rugby study to focus on attitude through the investigation of misunderstandings of concussion.(350) The cross-sectional survey employed modified questions from the RUCKAS-ST developed by Rosebaum and Arnett,(329) components of the Sye *et al*.(348) survey of youth rugby concussion understanding,(348) and drew upon the work of Cusimano *et al.*(364). Through a sample of 255 mostly male 11-17-year-old community based English rugby players, Kearney and See(350) initially stated that respondents demonstrated poor knowledge of the symptoms and treatment of concussion. They hypothesised that insufficient knowledge may result in young athletes not reporting concussions, a commonly stated theory at the time that has, as discussed above, now been challenged. The report showed more positive attitudes towards concussion disclosure than previously reported by Delahunty *et al*.(363) and Sye *et al.*(348) however, consistent with these studies, a substantial minority of the sample (at least 20%) reported poor attitudes. These attitudes involved players feeling a 'responsibility to play', particularly in relation to important matches.(350) This study and the investigation of specific attitudes towards rugby protective head gear by Barnes *et al*.(365) are the only publications into UK youth community level concussion attitudes to date.

Internationally, the most recent large-scale study of youth community level rugby player attitudes was conducted by researchers for the New Zealand Accident Compensation Corporation (ACC) in conjunction with the New Zealand Rugby Union's RugbySafe programme, discussed in detail below. The study reports data from 416 mostly male participants (94%) aged between 13 and 18 and was modelled on the survey developed by Sye *et al.*(348) discussed above. Despite a primary purpose of understanding the specific New Zealand ethnicity, geographic location and socioeconomics on awareness and reporting behaviour, this study's findings provide an up-to-date comparison for other rugby playing nations. The investigation highlights that 69% of players reported suspected concussion, however, only 31% indicated they had sought medical treatment.(366) The authors suggest that 38%, the number of players who did not seek medical attention, is a concerningly high figure given the risks associated with additional impacts. The researchers compare this figure favourably to that of Delahunty *et al.*(363) who, as discussed above, found 72% of respondents would play on in an important match despite a suspected concussion,(363) and on par with the 36% of youth players who would continue playing despite a suspected concussion reported more recently by Kearney & See.(350) It should be noted that such comparisons are indirect as despite some similarities in survey design, the questions employed to substantiate these figures differ.

The study reports that, as with previous research, (367-369) history of concussions and awareness of guidelines had no influence on whether a player indicated they should leave the field following a concussion.(366) This again reinforces evidence that attitude far exceeds knowledge as a determinant of concussion reporting and should, therefore, be the focus of risk reduction strategies.

Salmon *et al.*(366) conclude their discussion by highlighting the primary reason stated for non-reporting was that participants did not want to miss out on playing.(366) Although a common finding across a range of sports, the authors note that the specific nature of concussion management within rugby may have implications for this attitude. As the 21or 23-day policy of mandatory stand-down directed by New Zealand Rugby prevents players with a suspected concussion from returning to play, the authors suggest that this may also have the detrimental side-effect of increasing non-disclosure.(366) This policy, echoed across rugby playing nations, does not differentiate for symptom severity or duration. If it is an influence on the likelihood of disclosure as the authors suggest, its impact warrants investigation.

The studies documented above have begun to uncover the complexity of the triadic reciprocal relationship between athlete, environment and behaviour over time,(370) that shape the likelihood to disclose injury. Kroshus and colleagues, have applied the Theory of Planned Behaviour (TPB)(327) to rationalise concussion reporting attitudes.(371) As discussed above, the core tenant of TPB lies in the proposition that knowledge is an important predictor of behaviour only if it "links a behaviour of interest to positive or negative outcomes, to the normative expectations of important referent individuals or groups, and to control factors that can facilitate or inhibit performance of the behaviour." (327)(372)

For sports such as rugby, this implies that the greatest predictor of player behaviour is intention, a drive determined by attitude. Player attitude is shaped by the perceived consequences of choice, the cultural expectations/norms of the environment, and perceived behavioural control that they may have. (327)(372) In order to assess if the TPB model was able to predict the likelihood of concussion reporting, Kroshus *et al.*(371) conducted a survey of 256 male 18-21 year old Ice Hockey players.(371) Through the assessment of symptom reporting intention, perceived norms, self-efficacy, perceived outcomes of reporting, and concussion knowledge, Kroshus *et al.*(371) found that TPB was a relevant framework through which to explain concussion-reporting behaviour.(371) Despite not being suitable in isolation, as only a quarter of all behavioural variance could be explained, the researchers found predictive value in an individual's appraisal of the consequences of concussion reporting, the perception of whether teammates and most athletes would report symptoms, and confidence in their ability to report symptoms of a concussion, under a variety of challenging situations.(371) This led the group to highlight the need for psycho-educational interventions focused on short-term perceived athletic consequences. These include being held out of games, hurting the team's performance, and not being allowed to start playing or practicing when players think they are ready, as all were strongly linked with negative reporting.(371)

As with the wider sporting community, rugby concussion attitude understanding remains limited despite being essential to appropriate concussion prevention. Until this research gap is filled, the inference of attitudes reported by other sports to rugby remains. If, as described above, sporting cultures do play a significant role in shaping attitudes,(362) the distinct cultural norms of rugby leave such cross comparisons flawed. To fully appreciate the cultural drivers and resultant attitudes held by rugby players, a combination of more qualitative and quantitative research is, therefore, necessary.(355)(373) Through broader, higher quality research, the inherent divide between predicted and actual behaviour can be narrowed. Only then can suitably evidence based and effective risk reduction strategies be designed and employed.

### 2.8 Rugby Concussion Risk Reduction

Minimising the risks associated with concussion is a key requirement of rugby governing bodies and its key stakeholders. The sections below detail how some of the major rugby playing nations have approached concussion education before describing evidence surrounding neck strengthening and game characteristic changes. The section concludes by discussing potential future directions for concussion risk reduction in rugby with a focus on education and behaviour change, both key aims of this thesis.

#### 2.8.1 Rugby Concussion Education

As discussed above it is widely accepted that under reporting of concussion symptoms is widespread in athletic populations at all ages and competitive levels. (48)(348)(374) Rugby union is no exception. (10)(348)(375). The drivers behind such behaviour have been cited as a lack of knowledge of the risks and guidelines(374)(376) and/or unwillingness to report head injuries.(10) These features extend to parents, coaches, and officials who have all demonstrated a similar lack of concussion awareness. (1)(43)(375) Why these key stakeholders lack suitable concussion knowledge despite its perceived availability,(374) or choose to act against guidelines, is not well understood. In an attempt to address the short fall in perceived knowledge and behaviour, sport's governing bodies have developed and implemented a range of injury prevention programmes. Within rugby union, as with many sports, these have been based on the Consensus Statements on Concussion in Sport(376) and disseminated into practice by the governing body, World Rugby. Each major playing nation has in turn developed their own means to engage players, coaches, officials and parents.

### 2.8.2 New Zealand - RugbySmart

The New Zealand Rugby Union (NZRU) developed the RugbySmart injury prevention programme in 2001, aimed at reducing the number and severity of injuries in community rugby through education resources targeted at coaches and referees.(377) Developed in conjunction with the national public health insurance provider, the Accident Compensation Corporation (ACC), the RugbySmart programme initially focused on referees and coaches via compulsory workshops (377) and more recently, online video resources and app's.(378) Significant reductions in injury rates including serious spinal injuries(349) have been recorded since its inception, and as a result, a reduction in ACC claims has occurred.(377)

The RugbySmart programme primarily targeted coaches with the expectation that they are a key influence on player behaviour.(377) This decision was based on evidence supporting the coaches role in injury education and player safety attitudes.(379) Engaging coaches was also deemed more practical than targeting the far wider playing population.(377) The workshops initially comprised of practical participation activities, video presentations and written materials, with paper-based components more recently replaced by online resources. In 2017 the programme was expanded to encompass direct player education via online safety courses, health provider engagement through concussion management tools and a rugby specific warm up guide based on the FIFA 11+ injury prevention programme.(380)

Due to the unique nature of the AAC's engagement in sports injuries, RugbySmart is the only rugby injury prevention programme to include a continual nationwide injury prevention strategy and data collection process.(349) With data on stakeholder attitudes through to injury epidemiology, its efficacy undergoes regular appraisal which informs programme amendments.(378) When RugbySmart introduced the Concussion Management Education Programme (CMEP) in 2003 its effectiveness could be evaluated against the amount of head injury claims the AAC received. Over the course of its first 2 years, a 10.7% reduction in head injury insurance claims were filed against a backdrop of growing participation.(381) This led to a saving of $690,690 USD with a $12.6 USD return for every dollar spent on education implementation.(377) In 2020 the lead researchers behind the development of RugbySmart published a commentary on the challenges and lessons learnt during its implementation over the last 10 years. (378) The evaluation demonstrated continued positive return on investment with 3.94 $NZ for every dollar spent. Moreover, reductions in injuries resulting in long term or permanent disablement fell whilst player availability rose.(378)

Aside from the public health benefits of improved head injury education, the financial implications of head injury prevention has driven NZRU to a standing where the nation is considered the bench mark for both rugby injury data collection and validated prevention strategies.(381) Despite this its application has not been without challenge. As the data used is primarily based on insurance statistics it does not encompass injuries unclaimed for.(382) Claimant decisions can be influenced by economic factors and adjustments to injury definitions, uncontrolled by NZRU, further influence comparability. Although a natural result of large and continued data collection, such factors can impact intervention validity assessment. In addition, The RugbySmart programme did not benefit from pre-intervention baseline knowledge and attitude assessments that would have enhanced its efficacy validation.(382) This appears a common trend in injury prevention schemes,(383)(20) perhaps driven by governing body desire to address risks expediently.

### 2.8.3 South Africa - BokSmart

BokSmart forms the South African rugby union (SARU) National rugby safety programme and is modelled on the NZRU RugbySmart concept.(384) BokSmart was introduced in 2009 and is comprised of mandatory biennial workshops and video resources aimed at coaches and referees. This format was employed to ensure that injury assessment and management was standardised and uniform nationwide.(385) BokSmart is divided into four areas; 1) Compulsory free biannual rugby safety workshops for coaches and referees, 2) The BokSmart rugby medic programme designed to educate non-medically trained personnel focusing on those from under privileged areas, 3) the BokSmart Spineline, a dedicated service for head and spinal injuries based on pitch side emergency support and transportation, and 4) online educational resources.(386)

The efficacy of the system has been assessed through data collection of acute spinal cord injuries, traumatic brain injuries and cardiovascular events pre- and post-intervention. When assessing the impact of BokSmart on catastrophic injury rates, Brown *et al.*(2016)(349) used a Poisson regression to compare pre BokSmart injury rates (2008/09) with post implementation rates (2010/13). The authors cite using a Poisson Regression over the linear predictors employed within the initial RugbySmart serious spinal injury evaluations(349) due to the limited amount of pre intervention data.(349) The study reports 2.5 less serious injuries for junior players per year (incidence rate ratio: 0.6, 95% CI:0.5-0.7, $p<0.000$) and a non-significant increase of 1.3 injuries per year in adult players (incidence rate ratio: 1.2, 95% CI:0.7-2.0, $p<0.481$). The authors acknowledge that the study design assumes BokSmart is the only variable that could have affected injury rates, and that this is not ‘strictly true’.(385) However, the authors defend the methods used by citing the large potential influence of the programme and how it assimilates rule changes into its output.(385) Despite this, rule changes implemented within the data collection period for both injury prevention and aesthetics, are designed to affect the physical dynamics of the game. When coupled with the small pre intervention period (two seasons) and the resulting choice of pre/post intervention over linear analyses, the accuracy of the results could be questioned. This leaves Brown *et al.*(385) unable to draw any distinct conclusions as to the BokSmart programmes impact on spinal cord injuries.(385)

Additional research has been conducted by Brown *et al.*(387) to assess the impact of BokSmart coach directed injury prevention education.(387) Through questionnaire completion of 2279 junior and 1642 senior players, Brown *et al.*(387) conclude that receiving injury prevention education was significantly associated with correct injury management behaviour by players.(387) This appears to support the efficacy of the BokSmart program, however participants reported behaviour is conflated with actual behaviour, an unavoidable feature of survey and questionnaire based investigation, which should be clearly defined. Brown *et al.*(387) do highlight that the timing of the education received was not assessed, a potentially important factor when considering education intervention efficacy.

In 2014 the BokSmart programme introduced the 'Safe Six' junior injury prevention warm up. This programme echo's similar interventions introduced in New Zealand, Australia and the UK. The warm-up was designed to target six 'high risk' areas of the body through improved strength, balance and joint control with the overall goal of reducing the rate and severity of injury.(388) Data regarding the programmes efficacy has not been published to date. When further evaluating the impact of BokSmart coach and referee education courses in 2020, the same research group reported less than encouraging findings; low knowledge acquisition was found, unrelated to previous course attendance or more years of rugby experience.(389) The researchers cite a ceiling effect driven by high pre-course scores as a potential driver of these findings. In 2021 SARU launched an online version of BokSmart 6 Rugby Safety Course as part of the *My BokSmart* App. The SARU state the aim of the app is to extend the reach of the programme and offer participants the convenience to complete the course from anywhere at any time.(390)

### 2.8.4 England – 'Don't be a HEADCASE'

The RFU launched the 'Use Your Head' concussion and head injury awareness campaign in 2007.(18) The scheme developed into the online concussion programme 'Don't be a HEADCASE' (DBaH) in 2013 as part of the wider RugbySafe(27) injury prevention initiative. Aimed at a broader audience than the New Zealand RugbySmart programme, DBaH targets community level coaches, teachers, parents, players and match officials, with the programme based largely on online educational video resources. For the elite and professional levels of the game, the RFU introduced a mandatory concussion education programme including face-to-face education to England representative, Premiership, Championship men's and women's players, Premiership and Championship coaches, support staff and referees in 2014.(391) Outside of elite levels, concussion education has not been mandated for administrators, coaches and players but included within all RFU led community programmes.

DBaH was developed by the RFU Concussion Risk Management Group with the support of an independent concussion expert panel providing advice on concussion policy and emerging research.(392) The DBaH module is cited as complying with NHS guidelines, Sport and Recreation Alliance National Concussion Guidelines for the Education Sector, the International Concussion in Sport Consensus Statements and World rugby guidelines.(18) Although defined under the headings 'Adult Coach', 'Player', Match Official' etc., the online module content is uniform across the stakeholders. The DBaH module is based on an abbreviated version of the World Rugby established ‘7 R’s’ principle with DBaH emphasizing the four R’s of recognise, remove, recover and return. The module guides the participant through an audio-backed interactive course with the participant required to click on icons that open to reveal text and audio description.(393) Without opening all icons, the participant cannot access the next education section. At the end of the module the participant conducts a multiple-choice quiz. If, on completion of the quiz, questions have been answered incorrectly, the participant is required to repeat the quiz correctly in its entirety, before completion.(393) The RFU does not currently collect data from quiz completion. Coaches are required to complete the online module prior to gaining any RFU coaching qualification, although such qualifications are not mandatory to coach within English community rugby. Similarly, players of all ages at Community levels are not mandated to complete the module for participation. All stakeholders are however encouraged to complete the module. Although not tailored appraisals of a particular risk reduction intervention, the on-going community and professional injury surveillance projects discussed in section 2.5.6 have provided reference points for multiple law amendments discussed below (section 2.8.5) and trials implemented by World Rugby over the last decade.(10)(213)(394) The DBaH programme has, to date, not undergone any formal appraisal to establish its impact on the knowledge or attitudes of players or key stakeholders at community rugby levels.

### 2.8.5 Education Evaluation

When instigated in 2001, The New Zealand RugbySafe programme based its structure on the injury prevention principles outlined by Van Mechelen *et al.*(46) More recently incorporated into intervention Mapping (IM) protocol,(341) As highlighted above, The Van Mechelen principles state that for an injury prevention intervention to be effective, it needs to a) establish the problem, b) establish the aetiology and mechanism of the injury, c) introduce the preventative measure(s) and d) evaluate the effectiveness of prevention strategies by repeating step a).(46)(see section 1.2.5 and Figure 1.3) When conducting a 2017 systematic review of education programmes to prevent concussion in rugby union, Fraas *et al.*(381) concluded that only the RugbySafe and BokSmart programmes have completed all four steps.(381) The systematic review also points towards evidence that mandatory education training for coaches and referees is an effective approach for disseminating knowledge about concussions to athletes and parents.(381)

Developing, implementing and then evaluating the effectiveness of concussion reduction programmes, in an environment where injury epidemiology is poorly defined, is highly challenging.(383)(395) For a conventional injury reduction process, the means of assessing an interventions effectiveness can be achieved through an observed reduction in recorded injuries.(395) Within concussion research, where 'reported' concussion rather than true prevalence is commonly measured, a potentially positive intervention may not lead to reduced incidence rates. Reported injury rates may well go up following a intervention.(396) This positive outcome could be conflated by stakeholders and the public as a rise in incidence. Until practical objective means of establishing concussion prevalence are found, other metrics to evaluate education efficacy have been used. This has commonly been in the form of standardised knowledge and attitude questionnaires and surveys that can be employed pre- and post-intervention. These can be used to observe changes in self-predicted behaviour whilst assessing actual behaviour and injury prevalence remains challenging. As highlighted above, several such tools have been developed and used across a range of sports(43)(329) and differing stakeholders.(1)(316) The majority, however, have not undergone the scrutiny of psychometric validity assessment(329), lack consistency of methodology limiting comparability(395), and may not evaluate the mediators between intention and behaviour.(397) These limitations are evident within rugby knowledge and attitude assessment where despite posing similar questions, limited uniformity of language has prevented direct data comparison or combination.(348)(350)(398) As a result, there is limited evidence to support the effectiveness of current concussion education within rugby.(381) In order to apply best practice this must be addressed.

### 2.8.6 Neck Strengthening

As discussed above in sections 2.5.6 an association between neck strength and concussion risk has been identified in the literature if not yet fully defined.(193)(194)(399) It would, therefore, seem a natural target for injury risk reduction intervention.(196) Despite neck strengthening programmes being consistently employed within professional contact sports to this end, limited evidence underpins such protocols.(399) The systematic review of strength and conditioning protocols for improving neck strength and reducing concussion incidence and impact injury risk in collision sports by Daly *et al*.(400) highlight this. Only three studies met design criteria from 2462 identified articles. Two of the studies were rugby based(401)(402) with one from American football(403). Two of studies found a significant improvement in isometric neck strength following intervention but none reported any impact on cervical spine injury risk. The review highlights the distinct methodological differences in study designs and the current a lack of evidence to support the use of neck strengthening interventions in reducing risk in adult sporting populations.(400) Despite these findings, the authors of a 2017 RFU led cluster randomised controlled trial found that school-boy musculoskeletal injury and concussion risk was lowered by a pre-activity movement control programme that included specific neck strengthening drills.(404) This study was followed by a matching investigation at men's community level rugby(405) with both forming the basis for World Rugby's ongoing Activate Injury Prevention Exercise Programme.(406) Due to the large amount of variables within these risk reduction programmes it is hard to establish if neck strengthening was the most impactful intervention. Future investigations could look to follow the methodology employed by Farley *et al*.(196) discussed in section 2.5.6 to better define neck strengthening's specific role within broader rugby playing populations. This would enhance understanding of the links between neck strength and concussion, and in turn, the most appropriate risk reduction interventions.

### 2.8.7 Game Characteristics

As public and academic concerns of the risks associated with sport related head injuries has grown, governing bodies have looked towards regulation changes to minimize risk, whilst maintaining the core features of their respective games. Minimising injury risks in this way is recognised as a ‘Top-down’ approach.(384) This process has been challenging for contact-based sports where forceful interactions are often central to their appeal. Boxing is the most pronounced example as striking the head in an attempt to ‘knock out’ an opponent is the defining tenant of the sport. It is, therefore, harder to mitigate the inherently associated risks whilst not fundamentally altering the activity. Following investigations supported by World Rugby (see section 2.5.10), Rugby Union’s governing body switched from safety measures that had previously targeted protection of the ball carrier, to that of the tackler, as research had identified that the tackler was at greater risk of head injury.(407) The infographic below was produced to highlight the rationale for the law changes and how they would be implemented by officials.(407) (see Figure 2.14 below)

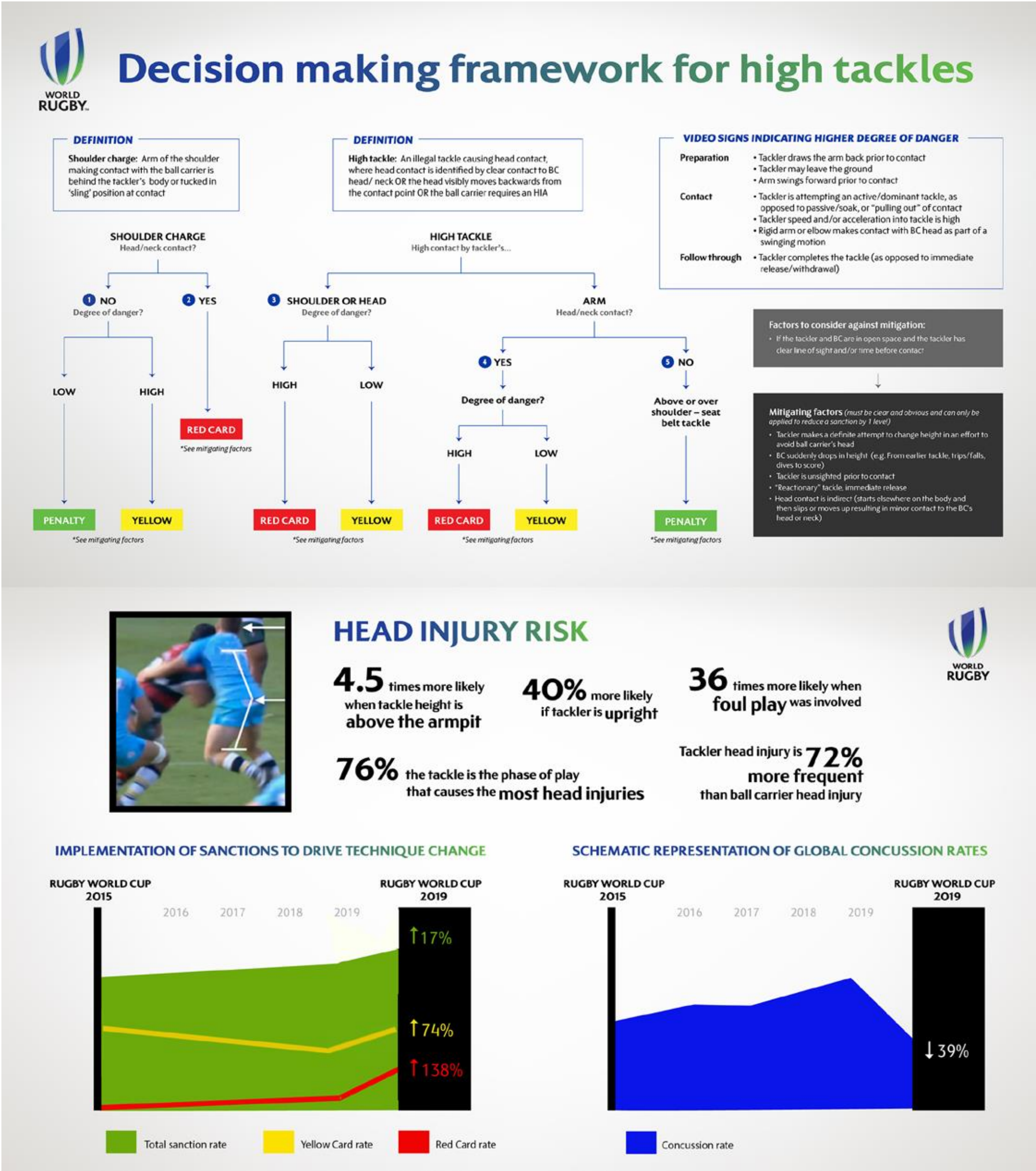


Figure 2.14 World Rugby decision making framework for high tackles infographic (407)

Within a publication titled "Getting tough on concussion: how welfare-driven law change may improve player safety—a rugby union experience", preeminent rugby researchers Martin Raftery and Ross Tucker, alongside World Rugby's chief medical officer Éanna Falvey, documented the governing bodies head injury risk management steps.(407) The publication describes how in 2017, sanctions awarded for head contacts were increased within the six major league competitions and all international matches. Sanctions included on-field penalties for any accidental and reckless head contact during tackles, plus more severe sanctions, yellow card (10 min temporary removal) and red card (permanent removal).(407) Following the 20171/8 season of implementation, tackle associated yellow cards increased by 41%, and red cards, issued for high-danger tackles such as a shoulder charge direct to head at high speed, increased over eight-fold.(407)

Following law enforcement intra and inter-competition refereeing inconsistencies, leading to media criticism, World Rugby developed and introduced the High Tackle Sanction Framework (HTSF) for the 2019 U20 World Championship and following Rugby World Cup.(408) Despite seeing tackle associated concussion rates reduce by 37% compared with the global average,(407) the World Rugby Research Unit (WRRU) later acknowledged that in-game high-tackle penalties had failed to influence behaviour change, even though these in-game penalties had increased significantly (58%).(407) Raftery *et al.*(407) states that in practical terms, this increase was equivalent to only one extra high-tackle penalty every second game, a sanction too infrequent and lenient to alter behaviour.(407)

In an attempt to address the limited impact of this intervention, a trial was instigated within the second tier of English rugby union. The 12 teams of The Championship competed under standard tackle laws for 2018/19 league games and revised, lower height tackle laws during cup games.(409) The line of maximum tackle height was lowered from the ball carriers shoulders to a line between the armpits. Despite a 30% reduction in tackler contact with an opponent’s head and neck, tacklers in the lower tackle height setting suffered more concussions than tacklers in the standard tackle height setting. no overall reduction in concussion was observed.(409) In addition, the trial was challenged by compliance issues that lead to the trials eventual abandonment.(407)

Despite the apparent failure of the tackle height law amendments observed in this study, the expert group, composed of players, coaches and administrators engaged by World Rugby, used the findings to reinforce the notion that successful injury prevention is reliant on the intervention and resultant compliance by stakeholders to it.(407) In concluding their review of rugby law change experience, Raftery *et al.*(407) state that to support a prevention strategy, “a strong awareness campaign, a visible system that supports consistent application of the intervention (in this instance, HTSF) and open support by the sport’s governing body, is essential.”(407). It would, therefore, also seem appropriate that tackle law adherence behaviour change is included in future concussion risk education interventions.

World Rugby, like all sports governing bodies challenged by concerns over player welfare, are duty bound to assess, and where possible, mitigate their games injury risk. Trialling and amending game characteristics play’s an integral part in this process. Also essential is then presenting rigorous evidence so that stakeholders can make informed decisions as to what level of risk they deem acceptable. Figure 2.15 below details the World Rugby Research Unit (WRRU) concussion diagnosis, management and prevention research framework.


Figure 2.15 World Rugby Research Unit (WRRU) concussion diagnosis, management and prevention research. (410)

This framework is stated to underpin World Rugby's ongoing drive to manage head injuries with 'evidence not emotion'.(410) This should include further expansion into non-professional cohorts in the coming years to substantiate changes, rather than rely on top-down inference.

### 2.8.8 Risk Reduction Directions

Recent research has suggested that despite reported gaps in concussion knowledge, the greater influence on symptom reporting, suitable removal from play, and adherence to GRTP, is the attitude/beliefs of the stakeholder.(331)(411)(412) Despite this, the interventions discussed above focus largely on knowledge enhancement, rather than behaviour adjustment. Essential to the IM protocol,(413) the Socio-ecological model (SEM),(414) The Translating Research into Injury Prevention Practice (TRIPP)(415) and other similar risk reduction structures, is the identification of negative or unsafe attitudes and behaviours that can be targeted by interventions. Unlike law amendments and gameplay adjustments, these psychosocial interventions are described as 'Bottom up' by Viljoen and Patricios(384). Kroshus *et al.*(371) provides a working example of how identified player attitudes may be applied to education. The authors state that if a belief is held that concussion reporting and subsequent removal from play negatively impacts team performance, education informing players of how playing with a concussion can hurt a team's performance may be effective.(371) This rationale supports the premise that concussion-related knowledge transfer strategies need to reflect a population's unique beliefs to be effective.(376) Furthermore, as young player attitudes develop as they mature, this suggests interventions should be age specific. Supporting this premise, a

2015 examination of concussion education programs through scoping review, by Caron *et al.*(412) indicated that young athletes score worse on post-education assessment than older athletes.(412) Citing this and the differing symptom patterns and recovery experienced by younger sports people, the authors recommend that concussion education should be created, disseminated and assessed according to age group.(412)

In addition to educational strategies to address non-disclosure, Kroshus *et al*.(371) highlights the need to evaluate and address environmental factors,(371) including the influences of coaches, trainers, management and parents.(371) Without a detailed understanding of the influence of these key stakeholders, evidence based intervention strategies cannot be implemented. Kroshus *et al.*(371) use an example of a player who feels if they report a concussion to a Coach they will permanently lose their team place.(371) A comprehensive risk reducing intervention, ensuring athletes get a fair chance to re-earn their spot in the line-up, is then cited as a coach directed potential intervention.

Kroshus *et al*.(371) conclude that educational strategies that address athlete concerns about the consequences of concussion reporting, shift perceived reporting norms, and increase reporting confidence in challenging situations, are needed.(371) Within many sports including rugby, this requires a far greater understanding of player attitudes than already exists. Once addressed, targeted interventions sympathetic to implementation constraints can be administered.

In addition to making the content of concussion education material reflect the target population, selecting the most appropriate format to engage each population appears key. Simply expecting stakeholders to stumble across or access injury prevention resources of their own volition would appear naïve.(416) The Centre for Disease Control and Prevention (CDC), the US federal agency charged with conducting and supporting health promotion, launched the "Heads Up!" concussion prevention program in 2016.(417) Following initial launch as an online resource, the CDC "Heads Up!" toolkit now includes social media platforms, video streaming channels, podcasts and a mobile app.(417) The expansion of the programme to cover as many avenues for dissemination as possible reflects findings that suggests having heard of the "Heads Up!" campaign was significantly associated with how important Coaches thought paediatric concussions were ($p$=0.0133, 95% CI=0.0590-0.4960).(418) This implies that without penetrative outreach, even the most targeted, evidenced based educated strategies impact will be limited. As discussed above, once established, addressing the key knowledge, attitude and cultural factors that influence concussion safety should be a primary goal for sport's governing bodies. Education strategies can be effective to this end if they are suitably structured, validated, targeted, and reach their intended audience. Considering the limited amount of injury prevention models that incorporate these features that are used in sports injury prevention,(419) it would appear this is easier said than done. Just as the intervention efficacy assessment discussed above and highlighted by Fraas *et al.*(381) would appear integral to risk reduction, models that create a framework for behaviour change in health have been presented. (see section 2.8.5) Considering the complexity of this psychosocial field, basing the attitude and intended behaviour change needs highlighted above on such frameworks would appear prudent.

Underpinned by the pioneering self-efficacy research of Albert Bandura, (370) one such model that has gained traction in health behaviour modification(416) is the Health Action Process Approach (HAPA) developed by German psychologist Ralf Schwarzer.(420) (see Figure 2.16)

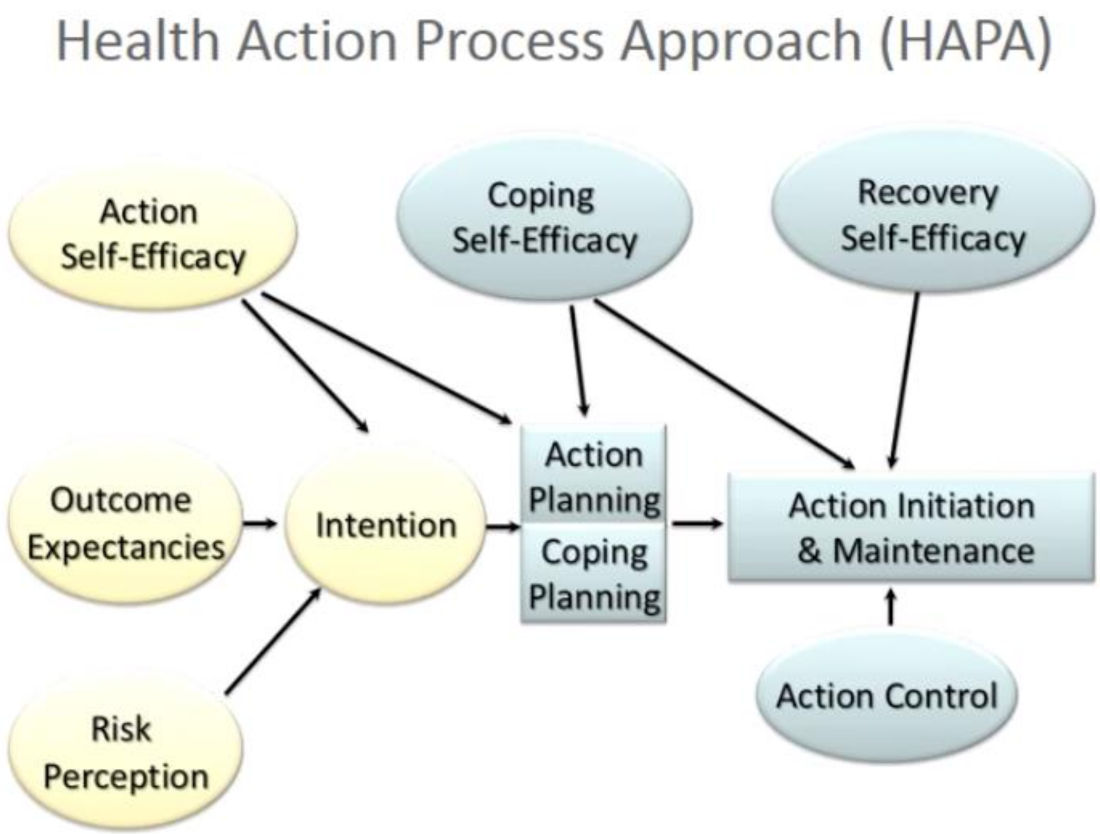


Figure 2.16 The Health Action Process Approach (HAPA) R.Schwarzer (2012)(420)

The HAPA theory describes how people begin to engage in health promoting behaviours. The model depicts two overarching phases. Firstly the ‘intention’ to change phase followed by the 'action’ phase, where intention is transformed to behaviour. The model highlights the associated multi-factorial influences at each phase. With these influences defined, researchers can then seek an understanding of a populations associated attitudes, and then develop interventions that encourage the transition from pre-intention to action. Although such frameworks cannot fully bridge the knowledge gap researchers face between intended and actual behaviour, creating a structure to assess the contextual and individual drivers can be beneficial. Such frameworks also have the potential to be contextualised through deconstruction to enable specific drivers to be evaluated.(416)

Rugby, a sport synonymous for promoting a distinct culture, values and attitudes, has many areas where assessment in this way could help understand stake-holders’ behavioural drivers. Sport’s governing bodies commonly cite their unique unifying values and attitudes but appear unable to fully define them, or build targeted interventions to modify them. If governments and sport’s governing bodies are to succeed in developing unified and validate concussion risk reduction programmes the incorporation of behaviour change and intervention efficacy frameworks discussed above would, therefore, seem an imperative.

## 2.9 Literature Review Conclusions

Over a five-fold increase in concussion related publications occurred between 2009 and 2019.(51) Fuelled by media scrutiny and heightened public awareness, governing bodies and academic groups have increased understanding of this challenging pathology greatly. However, despite concerted efforts and a growing evidence base supporting the King-Devick Test, no fully validated objective diagnostic tool has reached the sporting arena. Saliva based testing appears to be the most likely candidate to fill this vacuum at elite levels and as such, remains a primary objective for the concussion assessment research community.(241)(421) If and when such a tool is validated, its utility must then be established at community and youth levels. This will require further investigation and for it to be highly accessible. Developments in occulo-motor assessments may still become the most practical objective assessment tool in the community if saliva testing is not readily available. Further investigation that assesses the K-D Tests validity with UK community rugby may make this possible. The test may also provide a means to help establish individualised GRTP programmes alongside other tools, if repeated daily testing protocols can be substantiated. If saliva testing does become the gold standard at elite levels, it could be used to help validate a less expensive and non-medically driven tool based on other physiological assessments such as oculomotor function as with the K-D Test. Until such tools have been developed and validated, subjective decision-making will remain intrinsic to identification, treatment and suitable RTP at community levels. This could leave community youth rugby concussion incidence rates poorly defined.

Within rugby, the World Rugby backed developments made in gum shield accelerometry described in section 2.3.2, may also reveal more about the game’s concussion risk factors.

(112) If a standardised methodology appears, gum shield accelerometry could then be combined with saliva-testing and oculomotor function to reveal a fuller appreciation of the game's risks than previously achieved. The continued use of such measures could also help to validate risk reduction interventions such as neck strengthening or law amendments. Gum shield accelerometery may also reveal more of the efficacy of community level concussion identification. Commonly conducted by volunteer Coaches and Emergency First Aider's, how well these key stakeholders are able to identify concussion remains unknown. When heightened concussion incidence data resulting from gum shield accelerometry use is compared with volunteer interventions, missed potential concussion levels could be established. This form of comparison could also be used to further establish suitable player self-reporting rates, a similarly poorly understood occurrence.

Whilst research groups continue to explore the physiological aspects of SRC, psycho-social research surrounding concussion attitudes, knowledge and culture has also increased. The research presented to date suggests that attitude change rather than knowledge retention should be the primary focus for player concussion education.(411)(422) Despite this, limited investigation has occurred to underpin this hypothesis. Further understanding of youth rugby player knowledge attitudes is required to substantiate or refute this and to provide a means of measuring attitude change after intervention. With continued focus on both the subjective and objective aspects that surround SRC, future research could support evidenced based practice to foster uniformity of guidelines and education programmes across sports and nations. Currently the tools and rationales used often lack a suitable evidence base and their impact is, therefore, indeterminate. This fails to complete the final stages of common injury risk reduction frameworks that require an interventions effectiveness to be assessed.

The concussion challenges and associated evidence described above have led the author to establish a series of overarching hypotheses. Firstly, that youth concussion incidence has been significantly underreported and that the K-D test has the potential to both assist in addressing this, and as potential tool for parentally led concussion symptom assessment. Secondly, that EFA's are poorly appreciated and underutilised actors in concussion identification, management and education within youth community rugby. Lastly, that the understanding of, and relationship between concussion knowledge and attitude within UK youth community rugby union players is not suitably well established enough to ensure that the highest possible levels of safety are met. This thesis attempts to address shortcomings in concussion incidence understanding, assessment tool limitations, key stakeholder demographic, knowledge and attitude understanding, and educational deficiencies to this end.

# CHAPTER THREE

## Study One

### Reported concussion incidence in youth community rugby union and parental assessment of post head injury cognitive recovery using the King-Devick Test

This study has been published by the Journal of Neurological Sciences 388 (2018) 40-46.

### 3.0 Overview

Study One was conducted between 2014 and 2018 and aimed to investigate the frequency of reported head injuries in youth community rugby union and then establish the efficacy of the K-D Test for baseline and post injury assessment by community level medical staff. It would then establish the efficacy of the K-D Test for cognitive recovery monitoring by parents and describe the associated timescales. This study would be the first to report head injuries within youth rugby over multiple seasons and highlight the impact key stakeholders play in both the assessment and management process.

### 3.1 Introduction

Concussion has the potential to adversely impact both the long and short-term health of participants in contact sports.(11) As a result, concern over brain health has the potential to threaten participation rates.(50) The effects of head injuries have commonly been associated with rugby.(423) Head injury research has focused on professional players,(424) leaving a dearth of recent investigation at community and youth levels.(11)

At these levels, several barriers to concussion understanding and management within rugby remain.

The lack of practical, pitch-side diagnostic tools for concussion leaves its diagnosis shrouded in ambiguity and uncertainty.(333)(336) Assessment remains a primarily subjective process, reliant on symptom reporting. This places great pressure on those conducting assessments when asked to form a working diagnosis. As a result, the term 'suspicion' of concussive symptoms has become the basis for removal from play.(26) With no practical objective pitch-side diagnostic tools, those responsible for the welfare of players at grass roots levels have little to substantiate decisions, and the judgments of those at elite levels are left open to criticism.(336) The difficulties of concussion assessment and reliance on player symptom reporting are reflected in the variability of incidence rates within the literature. It is acknowledged that at youth levels neither incidence nor severity of head injuries has been thoroughly identified or understood.(5) This can be attributed to the heterogeneity of studies, inconsistent injury definitions used and lack of wide scale injury surveillance systems.(425) The impact of the lack of youth concussion understanding is heightened by the acceptance that young people are more likely to sustain concussion,(14) experience symptoms for longer,(15) and can suffer 'Second Impact syndrome' with potentially fatal consequences.(16) Young players, therefore, represent the most vulnerable playing population in the UK and worldwide. In an attempt to address these ongoing issues, the growing concussion research community has sought to establish the means to evaluate this complex pathology quantitatively, and validate suitable assessment tools for use in the field.(426) The K-D Test described in sections 1.2.3 and 1.6.5, has emerged as a tool proposed to add the critical dimension of vision to sports related concussion assessment(32) and be suitable for administration by non-medically trained persons.(427) Despite the growing body of evidence for its use,(32) the application of the K-D Test within rugby union has been limited. The current elite level Head Injury Assessment (HIA) has not included a visual based testing domain.(35) This prompted the RFU to conduct a trial of its use alongside the HIA for season 2016/17 and hypothesise that the K-D had the potential to impact beyond the professional game, if a validated assessment could be identified that could be performed by a non-medical practitioner.(35) The review concluded that the K-D was not a practical substitute for the current HIA process.(36) As described in section 2.6.5, the study did not, however, assess its intended use as part of a multimodal assessment battery(312) which may explain the studies finding.

The challenges surrounding youth concussion do not end with its identification and assessment. Governing bodies advocate a mandatory stand down period following head injury, followed by a GRTP protocol.(18) This process is designed to allow suitable time for cognitive and motor skill recovery and progressively build towards contact activities. Young players have shown a lack of knowledge of the GRTP and adherence to it across sports including rugby union has proven poor.(1)(47)(44) In addition, non-medically trained people currently have no identified means of objectively assessing cognitive recovery. At community youth levels where medical support is sparse, parental engagement is required to oversee GRTP. Parents have, unfortunately, shown limited engagement within the management of concussion at community rugby levels.(1) If these key individuals do not feel they have a responsibility to treat concussion, it has been suggested that they will be unlikely to demonstrate any reasoned or planned action in the event of injury.(1) Whether actively involving parents in concussion recovery encourages greater parent/child engagement, and in turn, adherence to the GRTP process, remains to be investigated.

## 3.2 Aim

The aims of this study were firstly to describe the frequency of reported head injuries in youth community rugby union and then establish the efficacy of the K-D Test for baseline and post injury assessment by community level medical staff. Secondly, it aimed to establish the efficacy of the K-D Test for cognitive recovery monitoring by parents and describe the associated timescales.

## 3.3 Method

### 3.3.1 Participants

A prospective cohort study was conducted at a community level rugby union club. This encompassed all registered and active junior players between under nine and under 18 age grades (U9-U18) (N=489) over four seasons. EFA’s, parents of players with a recognised first aid qualification assigned to each team/squad, were educated on the study through direct email and by direct communication with the researchers. The EFA’s involved all completed a level three Qualsafe awards and HSE approved, Emergency First Aid at Work qualification.(428) The one-day (six hours of contact learning) course qualifies the individual as an emergency first aider for three years. Despite this qualification period, the rugby club involved asks all EFA's to conduct the course that is held onsite, free of charge, annually. In addition to the basic first aid components specified by the course, rugby specific aspects have been added including head injury scenarios and concussion symptom recognition, as requested by the Club. All EFA's were required to pass the RFU HEADCASE online concussion module(18) prior to course conduction.

As the first responders pitch-side to any potential injury, The EFA's primary role was to 'recognise' and 'remove' those they suspected of sustaining a head injury as directed by the Consensus Statement for Concussion in Sport.(429) Parents and players where then to be directed to the onsite Duty First Aid Therapist (DFAT), in this case, a Health Care Professions Council (HCPC) registered physiotherapist for further evaluation. As advised by the RFU,(27) all DFAT's were sports trauma management qualified and had passed the coaches online RFU concussion module. Parents and players were informed of the study through the online registration process, posters, website information and direct communication from the researchers with each age group. DFAT's were informed that the testing process would be no different from RFU head injury management guidance and that the K-D Test would be an additional supplement.(18) Parental consent to participate was gained during the rugby club online registration process at the beginning of each season. Parents were asked to actively tick a box to consent to their child's baseline and post injury data to be recorded and used for research purposes. No parents declined consent for their child to participate. St. Mary's University Ethics Committee approved all procedures.

### 3.3.2 Procedure

### 3.3.3 King-Devick Test

The K-D Test requires a player to read aloud a series of random single-digit numbers from left to right. The test pack includes one practice (demonstration) and three test cards varied in number format on a six by eight-inch card. (see section 2.6.11) Players were asked to read the numbers aloud from left to right across the card as quickly as they could without making any errors using standardised instructions printed on the test cards. All test card packs had identical number and number placement formats. The time(s) were logged for each test card along with the number of errors made.

### 3.3.4 Baseline Testing

K-D baseline testing was conducted during the first four weekends of the 2013/14 season and repeated for the following three seasons. Two to four testers (EFA's and DFATs), conducted the baseline tests at a canopied pitch-side desk. Noise and environmental factors have been shown not to affect K-D Test performance.(430) Targeting one age group at a time, the lead researcher extracted players from rugby training to conduct the test. Coaches were asked not to commence contact-based activities until all players had conducted baseline testing. This cycle continued until all players from the age group had been tested. This method ensured baseline testing would mirror the physiological state of the player during post injury re-testing and include the positive effects of vigorous exercise observed on K-D Test scores.(32)

Players $\leq$ 13 years conducted the demonstration and test cards I & II whilst those > 13 years completed the demonstration and all three test cards. The recommended age divide for card number conduction changed to 10 years of age during the course of the study. The 13 years of age divide was maintained however to permit continuity of results. The K-D Test recommends two consecutive tests to negate any mild learning effect that has been observed.(32) Only one baseline test was used in this study as at no other time would the test be repeated twice in the same day, either directly after suspected injury or during the re-testing process. In support of this methodology, test-retest reliability has been shown to be very high between repeated baseline scores with minimal variability.(32) small weighted mean combined improvements of 1.8s have been observed when repeating the K-D Test, considerably lower than the mean observed worsening in scores post head injury of 4.8s.(32) Test scores were collated onto a database by the lead researcher. Players completing the test (n = 489) were logged against the registration database and those who missed baseline establishment were contacted to conduct a test after starting active participation.

### 3.3.5 Following suspected head injury

If a pitch-side EFA, coach or parent suspected a head injury on-site, the player was guided to the first aid room for assessment by the DFAT. The DFAT conducted the standardised concussion management process advocated by the RFU, followed by the K-D Test. If present, the parent/guardian was educated on the on-going re-test process along with the GRTP. If not in attendance, the lead researcher would telephone the parent/guardian to inform them. The parent/guardian was provided with the players baseline score and was asked to oversee the repeating of the K-D Test. Every time the test was repeated, the discrepancy between baseline and current score was recorded. When the participant surpassed the baseline scores for all test cards, they had completed the K-D retest process. The number of days taken to return to baseline was recorded.

The DFAT was available to answer any questions regarding the player's symptoms and the RFU defined GRTP process. Once the 14 day stand down and eight-day GRTP process was completed, parents were asked to feedback K-D scores to the DFAT and in turn, to the lead researcher, before their child returned to club representative contact-based activities. Repeat home testing using the K-D was not influenced by baseline to post injury scores and as such the test was not considered a diagnostic tool from which to inform RTP decisions. In accordance with governing body guidance, suspicion of concussion remained the overriding trigger for removal from play and the GRTP followed regardless of K-D testing.

### 3.3.6 Data Analysis

All data were entered into a Microsoft Excel spreadsheet. For each age group, baseline median and interquartile ranges were calculated. Reported concussion rates were calculated per 1000 hours of match play with associated 95% confidence intervals. Differences between age group rates were assessed using rate ratios (RR). A Kruskal Wallis one-way ANOVA followed by post hoc Dunn's tests was used to determine any differences in K-D time between age groups. Some investigators have suggested that a three second worsening of K-D performance could be used as a marker to assist with the identification of a concussive injuries as part of a boarder medical evaluation.(431) As a result, baseline and post injury test discrepancies were split between < 3 seconds and $\geq$ 3 seconds, with a Spearman's correlation used to determine any association between baseline and post injury test discrepancy and days to recovery. Significance was set *a priori* at p<0.05.

## 3.4 Results

### 3.4.1 Baseline Data

Table 3.1 shows the median baseline K-D Test times recorded for each age grade. The Kruskal-Wallis H Tests were used to determine differences in median times between the U9 to U13 age groups and U14 to U16 age groups. Each age groups baseline data distributions were similarly shaped. When examining the U9 to U13 groups, baseline performance significantly differed ($\chi^2$ = 80.1, df = 4, p <0.0001). Dunn's test Post hoc analysis revealed that median baseline KD performance in the U9 age group (37.3 s) was significantly slower than the U10 (34.9 s), U11 (33.3 s) U12 (32.6 s) and U13 cohorts (31.7) (p < 0.05). Additionally, the U10 age group baseline performance (34.9 s) was significantly slower than the U12 (32.6 s) and U13 (31.7s) age groups (all p< 0.001). When examining the U14 to U17/18 groups, baseline performance also significantly differed ($\chi^2$ = 22.2, df = 3, p <0.0001). Post hoc analysis revealed no significant differences in observed baseline performance with an age group and the cohort directly above in age, but just as with age groups U10 and above, significant differences where observed when skipping an age group, U14 with U16 ($\chi^2$ = 2.7, p = 0.077), U15 with U17/18 ($\chi^2$ = 4.4, p = 0.002.)

Overall, 49 players reported to the onsite therapist following suspicion of concussion. (Table 3.2) Three players did not undergo parental re-testing, two of which were at boarding schools representing a 93.8% parental engagement rate. This rate rises to 98% if the mitigating circumstance of child boarding is accounted for. The number of players reported for further assessment remained consistent across the four-season period. ($\chi^2$ =0.22 , P=0.9735)

### 3.4.2 Head Injuries

Thirty-eight injuries occurred during standardised competitive match play whilst eleven occurred during training. The U12 age group reported five head injuries from variable time, small-sided games and training. No injuries were reported in the U9 to U11 age groups. Combined reported match head injury incidence across all age groups was 12.7 (95% CI 9.2 – 17.5) per 1000 match hours (Table 3.3). The highest reported match head injury incidence rate was 23.1 (95% CI 9.6 to 55.6) per 1000 match hours in the U12 group, and the lowest observed in the U15 (11.1 [95% CI 5.0 to 24.7] per 1000 match hours), and U16 (11.1 (95% CI 5.3 to 23.3) per 1000 match hours) groups. Table 3. Shows RR (Risk Ratios) for each age group compared through Chi-squared tests with the highest reported incidence cohort (U12) (1.0). Trends were apparent between age group incidences, although none were significant. Table three shows the median discrepancy in seconds between initial post-injury onsite test and last recorded baseline (7.3 s). Training incidence rates were not calculated due to the weekly variability in training time and player attendance.

Table 3.1 Median baseline K-D times (s) at age grade levels U9 to U17/18

| **Age Group** | **U9** | **U10** | **U11** | **U12** | **U13** | **U14** | **U15** | **U16** | **U17/18** |
|---|---|---|---|---|---|---|---|---|---|
| Card 1. Median Time (IQR) | 19.2 (15.3-20.9) | 17.3 (15.1-19.7) | 16.5 (14.8-18.9) | 16.0 (14.3-18.5) | 15.7 (14.0-17.7) | 14.9 (13.3-16.5) | 14.1 (12.8-15.8) | 13.9 (12.7–15.6) | 13.5 (12.3-15.2) |
| Card 2. Median Time (IQR) | 18.2 (15.5-21.1) | 17.6 (15.4-20.1) | 16.8 (15.1-19.4) | 16.5 (14.4-19.1) | 16.0 (13.9-17.9) | 14.2 (12.9-16.2) | 14.1 (12.8-16.6) | 14.1 (12.7 -16.3) | 13.9 (12.3-15.7) |
| Card 3. Median Time (IQR) | - | - | - | - | - | 15.6 (13.9-17.4) | 15.2 (13.6-17.3) | 15.0 (1376-17.2) | 14.6 (13.0.-16.4) |
| Total median Time | 37.3 | 34.9 | 33.3 | 32.6 | 31.7 | 44.7 | 43.4 | 43.0 | 42.0 |
| N= | 88 | 92 | 79 | 99 | 46 | 67 | 97 | 79 | 80 |

Table 3.2 All reported head injuries (match and training) by season and age group.

| **Age Group** | **U12** | **U13** | **U14** | **U15** | **U16** | **U17/18** | **Total** |
|---|---|---|---|---|---|---|---|
| Season 1 | 2 | 1 | 1 | 3 | 2 | 3 | 12 |
| Season 2 | 1 | 1 | 3 | 2 | 4 | 2 | 13 |
| Season 3 | 2 | 0 | 2 | 2 | 2 | 5 | 13 |
| Season 4 | 0 | 3 | 1 | 1 | 3 | 3 | 11 |
| Total | 5 | 5 | 7 | 8 | 11 | 13 | 49 |
| Match injuries | 5 | 4 | 5 | 6 | 7 | 11 | 38 |
| Training injuries | 0 | 1 | 2 | 2 | 4 | 2 | 11 |

Table 3.3 Incidence of on-site reported head injuries per 1000 match hours by age group.

| Age group | U12 | U13 | U14 | U15 | U16 | U17/18 | Total |
|---|---|---|---|---|---|---|---|
| Total Matches played | 27 | 30 | 32 | 36 | 42 | 54 | 221 |
| Exposure (hr) | 216 | 260 | 400 | 540 | 630 | 945 | 2991 |
| Players assessed | 5 | 4 | 5 | 6 | 7 | 11 | 38 |
| Incidence per 1000 match hours (95% CI) | 23.1 (9.6 to 55.6) | 15.4 (5.8 to 41.1) | 12.5 (5.2 to 30.0) | 11.1 (5.0 to 24.7) | 11.1 (5.3 to 23.3) | 11.6 (6.4 to 21.0) | 12.7 (9.2 to 17.5) |
| RR | 1.0 | 0.7 | 0.5 | 0.5 | 0.5 | 0.5 | |
| 95% CI | | 0.2 to 2.5 | 0.2 to 1.9 | 0.1 to 1.6 | 0.2 to 1.5 | 0.2 to 1.5 | |
| P | | 0.4335 | 0.3198 | 0.2655 | 0.2575 | 0.2542 | |
| $X^2$ | | (0.61) | (0.99) | (1.24) | (1.28) | (1.3) | |

Table 3.4 Number of reported head injuries, discrepancy time between first test and baseline, and days/tests to recovery with median and inter-quartile ranges across four seasons.

| | Head Injuries assessed by parents | Median discrepancy (s) first retest to BL (IQR) | Longest recovery (Days/tests) | Shortest recovery (Days/tests) | Median recovery (Days/tests) |
|---|---|---|---|---|---|
| Total | 46 | 7.3 (2.5 – 8.0) | 14 | 4 | 5.1 |
| Season 1. | 10 | 11.8 (2.8 – 19.3) | 14 | 3 | 7.2 |
| Season 2. | 13 | 7.0 (2.8 – 7.5) | 11 | 2 | 4.8 |
| Season 3. | 11 | 6.9 (4.2 – 7.3) | 6 | 2 | 3.5 |
| Season 4. | 12 | 4.3 (2.0 – 6.1) | 8 | 1 | 5 |

The days/tests taken to surpass baseline scores ranged from 1 to 14 days/tests, with a median recovery time of 5.1 days/tests (Table 3.4). A weak, insignificant correlation ($r_s$ = 0.25, p =0.0861) was found between discrepancies and the days taken to surpass baseline scores. Of the initial post injury tests recorded, discrepancies of over three seconds from baseline were observed in 30 cases (median difference 4.9 sec (IQR -4.2-4.7)). Discrepancies of less than three seconds from baseline were observed on 16 occasions (mean difference 1.67 sec (IQR-0.7-2.4).

### 3.5 Discussion

The aim of this study was to describe the frequency of reported head injuries in youth community rugby and to establish the efficacy of the K-D Test for baseline and post injury assessment by community level medical staff. The efficacy of the K-D Test for cognitive recovery monitoring by parents was then established.

#### 3.5.1 Baseline Data

Pre-season baseline scores were consistent with published studies.(32) U15 age group median baseline times (43.4 s) were similar to 15 year old Hockey players, (44.5 s),(432) as were median baseline times from U16/17 age group American Football players (43.0 s)(433) with counter parts in this study (43.4-43.0 s). Baseline comparisons with previous studies of under U13 children were prevented by the use of the two-card testing protocol. Although not directly comparable, the baseline data supports meta-analyses observations that link improving K-D Test times with increasing age. (32) When using the two-card testing protocol among the U9 to U13 age groups, notable improvements from U12 and U13 age groups were observed over the younger U9 and U10 age groups. No meaningful differences in baseline performance were noted between any age group over U10 and the next age group above. This pattern suggests that despite observable improvement with age, a one-year baseline span appears too brief to identify meaningful improvements when assessing mixed age cohorts. This validates the studies annual baseline testing methodology and could be used to support future baseline testing every other season.

### 3.5.2 Reported Head Injuries

The combined reported head injury incidence rate of 12.7/1000 match hours (95% CI 9.2 to 17.5) sits considerably higher the range of previously published youth rugby concussion risk.(11)(425)(216) This figure fits the trend of increased reporting of rugby head injuries over recent years.(10)(11) The figure is, however, lower than the 19.8/1000hrs match concussions reported within English professional rugby,(4) although it should be noted this figure represents a formal diagnosis of concussion and not suspicion/assessment as was used to define incidence within this study. Within amateur men's rugby union players assessed using the K-D Test, King *et al.*(304) report similar witnessed incidences rates of 10.9/1000 match hours (95% CI 4.5 to 26.2).(304) Interestingly this study also assessed players not perceived to show concussive symptoms, increasing the incidence rate to 45.9/1000 match hours (30.3 to 69.8), when discrepancies of >3 seconds from K-D baseline were used as a marker within a broader medical evaluation. This supports the rationale that concussion assessment should be multimodal(26) including cognitive/neurological aspects (434) and that the K-D Test is an efficient side-line assessment tool, but not a sole means to formally diagnose concussion.(34) Further research into the longer-term consequences of seemingly asymptomatic injuries is required.

The observed age distribution in reported match head injury incidence is contrary to the accepted norm of increased injury risk with age.(435) No head injuries were reported from the U9-U11 age groups. This may be a result of less contact exposure that incrementally increases with player age. The highest reporting of head injuries within U12-U14 age groups may be a result of several factors. First aiders and coaches may find identifying potential head injuries in younger age groups easier due to smaller pitch sizes and smaller player numbers, despite less contact incidents. They may also be more cautious when managing younger participants. As a result of the larger player numbers, pitch size, and the nature of the game, e.g., rucks and mauls, first aid observation may be more challenging within the older cohorts of the game. It should be noted that during the study period several amendments to age grade match rules occurred. Older players may also be more reluctant to seek assessment as has been shown with university age sports people.(436) A paucity of understanding of the knowledge and attitudes of first aiders and players means the validity of these hypotheses remains unsubstantiated.

### 3.5.3 Post Injury Assessment

Of the 49 post-injury K-D assessments conducted, none were equal to or less than previous baseline times, demonstrating a degree of impaired cognitive function in all injured players. The median discrepancy in baseline to initial post injury test of 7.3 (2.5 – 8.0) is higher than 4.8 s (95% CI: 3.7, 5.8; I2 = 0.0%; p = 0.58) reported within 2015 K-D meta-analysis.(32) The limited heterogeneity within the studies included, limited subject numbers and resulting high p values may, however, be responsible for the differences observed. Some investigators have suggested that a three second worsening could be used as a marker to assist with the identification of a concussive injury as part of a boarder medical evaluation.(431) This study found 16 participants initial re-test times fell under the three-second marker, despite all players reviewed demonstrating or reporting assessment prompting symptoms. These findings suggest there is no evidence to support specific worsening of K-D Test scores as a diagnostic tool for concussion, other than any degree of worsening in conjunction with other symptoms and tests. This is supported by meta-analysis finding of non-concussed control athletes who demonstrated improvements of 1.9 s (95% CI: -3.6 to -0.02; I2 = 0.0%; p = 0.99).(32) As a result, the K-D Test can be considered a valid test when used within a multi-modal framework including symptom reporting(37)(437) when utilised by the medical staff in this setting. Its utility also extends to non-medically trained individuals to assess cognitive function post head injury. This finding also substantiates the sensitivity of the single-test baseline method employed, as repeated test performance has been shown to only marginally improve speeds (303) and ,therefore, not effect post injury test sensitivity.

### 3.5.3 Parent Directed Assessment

As the K-D Test has not been previously used to plot cognitive recovery on a daily basis after head injury, the median of 5.1 days to return baseline is a novel finding of this research. This sits below the accepted figure within rugby that 80-90% of concussion symptoms resolve within 7-10 days.(18) It should be noted that the K-D Test only assesses occulo-motor function and, therefore, further symptom resolution investigation is required to determine when all concussion-inducing impairments have fully resolved. The range in days to cognitive recovery (1-14 days) in the current study reveals a wide variety in recovery times. Recovery times also show only weak correlation with baseline to re-test discrepancies. It would, therefore, appear unwise to consider post injury K-D Test performance as a marker for injury severity, but it can be a means to chart cognitive recovery after concussion. Coaches, medics and parents could use the K-D Test as an objective tool to measure cognitive recovery and substantiate when to implement active elements of the GRTP programme or learning activities. This could negate current blanket stand-down periods that have proved hard to enforce at community levels,(10) and may act to hinder rather than promote clinician-player interactions.(336)

Only three participants failed to report repeated K-D Test data, two of which were from children at boarding school away from close parental supervision. Parental engagement was 93.8%. This figure is far higher than previous studies to report parental-child communication regarding concussion.(1)(325) Through the assessment of 18 parents of rugby playing children, Clacy *et al.*(1) found only 27.8% felt they were responsible for ensuring their child's fitness to play, whilst only 22.2% felt they were responsible for concussion prevention including education.(1) This lack of perceived responsibility and engagement is concerning as parents play a primary role in shaping attitudes, behaviours and perceived norms of children regarding concussion,(325) Furthermore, concussion education is considered most effective when given in a family environment.(438)

Within this study the practical aspects of the home K-D Test process clearly promoted greater parental engagement. Initially parents were introduced to medical professionals creating communication channels and fostering parental responsibility. This link provided a vehicle to educate parents as to the risks of concussion. This is considered essential as parents who perceive a greater threat from concussion may be more likely to engage in safety related practices.(325) The use of the K-D Test may have also helped overcome what has been described as 'behavioural paralysis' that can ensue when health outcomes are perceived as highly threatening, but no risk reduction strategies are available.(439) In addition, it has been suggested that the parents of previously injured players may also become more aware of the importance of future symptom reporting as a result of observing the time it took their child to recover.(325) The engagement provided by the K-D Test would seem ideal in this capacity. Although it remains challenging to measure the impact of parental engagement on child concussion attitudes and behaviours, further studies could look to correlate parental-child concussion engagement with adherence to RTP protocols, player symptom reporting and wider school/club cultural norms.

### 3.5 Limitations

The primary limitation of this study, as with the majority of studies investigating concussion incidence, lies in the means of identification. This study does not purport to identify the incidence of concussion in youth rugby, but does identify the incidence of reported concussion symptoms. Player, EFA and medical staff actions, therefore, influence the results heavily. As has been previously been described by Roberts *et al.*(10) within UK men's community rugby,(10) the results may represent a 'minimum estimate'. Further research of coaches, medical staff and players attitudes and behaviours regarding concussion is paramount.

As with most un-supervised data collection, the accuracy of data collected through parental testing could be considered a limitation to this study. Despite evidence to suggest that the K-D Test can be effectively administered by non-medically trained persons,(427) the validity of data reported by parents could be brought into question. A means of increasing the validity of parentally supervised K-D Test scores may be to enforce a supervised test before a return to contact-based activities. Despite informing parents of the need to review their child before a full return, the addition of off-site, school and representative sport, and the limited contact between all supervisors, makes this process challenging to enforce. A child may sustain an injury at one site, either conduct a GRTP or not, and return to activity at another site without coaches, first aiders or medic awareness. If parentally garnered data is to be used as part of a concussion recovery process, clearance to play should include the validating of any such information. Until the means of recording and sharing head injury information across all representative bodies is established as part of the GRTP, the validating of home testing remains problematic and the efficacy of the GRTP process impaired.

The K-D Test also has the potential to be purposefully under-performed or “sand-bagged” by participants adding to the challenges listed above.(33) Whether this occurs with young players and if so, at what age, remains to be established. Until objective measures are employed that cannot be participant influenced, symptom reporting will remain the primary means to diagnose concussion and to establish incidence rates.

### 3.6 Conclusion

This study is the first to detail the incidence of reported head injuries in a UK youth community rugby population over multiple seasons. The results demonstrate that the K-D Test is applicable on a large scale for community level youth rugby when employed by non-medically trained individuals and within a multi-model assessment by medical staff. The finding that a one-year baseline span appears too brief to identify meaningful improvements when assessing mixed age cohorts suggests that seasonal K-D baseline testing is a suitably sensitive protocol for youth sporting applications. This study supports the findings of youth and adult K-D Test meta-analysis within younger cohorts, that identify the K-D Test as a rapid, reliable, sensitive and specific test for concussion.(32) The K-D Test was not, however, used as a means to establish suitable removal from play or a diagnosis, and was employed alongside the currently RFU advised SCAT assessment. Medical staff, Coaches and EFA’s can be actively engaged in the testing process and parents are willing and capable of playing an active role in onward concussion management. Establishing the validity of any such parental involvement in concussion management does, however, require far higher levels of GRTP communication across sporting teams/schools than currently observed. The methodology employed may also point towards how individualised GRTP may be possible in the future. The testing protocol demonstrated daily the resolution of oculomotor function. If combined with repeat testing of other validated neurophysiological and cognitive functional tests, blanket stand-downs that may discourage disclosure(366) could be negated. Future investigation is needed to establish the drivers behind player, parent and EFA, attitudes and behaviours towards concussion and how tools such as the K-D Test can support decision-making.

# CHAPTER FOUR

## Study Two.

**Emergency First Aider's in English youth rugby union: Background, understanding and perceived role in the prevention, identification and treatment of concussion.**

### 4.0 Overview

The conduction of Study One highlighted the key role EFA's play in the assessment and management of concussion within youth rugby. Conducted during the 2018/19 season, Study Two aimed to identify the demographic of EFA's within English community youth rugby union by incorporating the socio-technical systems approach employed by Clacy *et al*.(1). It would then examine EFA understanding and perceived role/responsibilities of concussion management. This would help direct targeted education strategies and governance at local and national levels.

### 4.1 Introduction

Accurate diagnosis and management of pitch-side sporting concussion remains a challenge(38) due to the lack of a practical working definition of concussion (26)(440) and an absence of widely available objective diagnostic tools.(38)(441) This leaves clinical decisions underpinned by symptom reporting, and thus exposed to bias and ambiguity from participants(11) and assessors.(1) Furthermore, without accurate concussion incidence rates, data reliant on the accuracy of clinical assessment tools, injury risks cannot be defined and in turn targeted risk reduction strategies cannot be validated.(440) The difficulties in establishing accurate concussion incidence rates can be seen within English rugby union over recent seasons.(10) Year on year English rugby concussion incidence rates have increased at elite levels, potentially driven by the increasing sensitivity of concussion assessment tools, the lowering of the concussion threshold criteria, more accurate assessment application and rising stakeholder and media awareness. These developments have occurred within a sport without impactful changes in playing regulations or nature.

To address these issues at elite levels of rugby union, frequent alterations to head injury assessment processes have been implemented by World Rugby, and in turn the RFU. To limit the risks of undiagnosed concussive injuries, the RFU introduced video assessment to Premiership level competition in 2014. Players considered to have sustained a concussive injury, witnessed on video by a medic, could then be removed from play and undergo a Head Injury Assessment (HIA) discussed in section 2.6.3.6. At community levels, where the overwhelming majority of sporting participation occurs,(442) the comparative paucity of medical support magnifies the challenge of injury identification in this rugby playing population. (215)(443)

Within English community rugby union, Emergency First Aider's (EFA) are commonly responsible for observing potential injuries and making 'removal from play' decisions when trained medics are not present pitch-side.(444) The RFU minimum standards require EFA's to hold Level 3 First Aid Qualifications (based on the Regulated Qualifications Framework (RQF). These are commonly organised by employers who required designated EFA's in the workplace. The RFU run Emergency First Aid in Rugby Union (EFARU) Courses when requested by clubs and schools which meet these standards and are rugby specific. At youth rugby levels, one EFA is required per age-group for training, based on a ratio of one first aider to approx.40 players. For matches, one EFA is required per age group for U7-U8 and one EFA is required per match for U9-U18 fixtures.(444)

EFA's are frequently parents of players and the reliance on these key pitch-side individuals is a concern in light of the variability of concussion management knowledge at lower levels of sporting participation.(44)(445) To gain a greater understanding of the perceived roles of key stakeholders and wider rugby union management hierarchy in dealing with concussions, Clacy *et al*.(1) employed a socio-technical systems approach.(1) The authors describe the socio-technical systems approach as being based on the work of pioneering Danish safety science academic, Jens Rasmussen. Rasmussen's systems approach is underpinned by the rationale that injuries have numerous interrelated contributory factors that are influenced by the stakeholders within the system. Rasmussen (446). The authors state that the socio-technical approach employed attempts to understand the network of systemic contributory factors involved in injuries and engage in system reform, rather than focus on interventions specific to the casualty, a common trait of risk reduction frameworks. Within community rugby this could be demonstrated by attempting to understand and influence the processes surrounding head injury disclosure, over a focus on game alterations designed to limit head impacts.

In order to apply this approach and record all aspects of stakeholder roles and responsibilities, Clacy *et al*.(1) used questions structured around the Theory of Reasoned Action (TRA) Ajzen(327), TRA is an extension of the Theory of Planned Behaviour

(TBP) discussed in section 2.7.1.3 The TRA posits that the primary predictor of behaviour is a person's behaviour intention, with the 'reasoned' title implying conscious decision making over reflexive actions. Behaviour intention is influenced by stakeholder attitudes and subjective norms. to predict planned behaviour a thorough understanding of stakeholder attitudes and contextual social norms is required.

To achieve this, Clacy *et al*.(1) asked community based parents, coaches, players, referees and medics within a rugby setting to report their perceived roles and responsibilities in the prevention, identification and treatment of concussion through questionnaires.(1) Nearly two-thirds (61%) of parents indicated they had some role to play in concussion prevention, with 94% reporting that they could identify one or more symptoms of concussion. In contrast, only 33% of parents stated that they had a role to play in concussion treatment.(1) This sample did not encompass EFA's. Without a deeper understanding of these individual's demographic, understanding, perceived roles, responsibilities and attitudes towards concussion, their efficacy in assessing and managing head injuries remains unknown. This lack of insight limits understanding of their contribution within the rugby stakeholder injury management system and hampers the development of targeted head injury education strategies for this key population.

## 4.2 Aim

The aim of this study was to implement the socio-technical systems approach employed by Clacy *et al*.(1) to identify the demographic of EFA's within English community youth rugby union and examine their understanding and perceived role/responsibilities of concussion management. Short structure interviews were favoured over case study or focus group investigations in order to include the largest sample of participants. The findings could then be compared to other rugby-based stakeholders operating in a similar environment from Clacy *et al's* original findings.

## 4.3 Methods

### 4.3.1 Setting

Five mini and youth rugby union tournaments held at a community level Club in the South East of England provided the setting for investigation. During 2017/18, instructions for designated EFA's to attend a site medical briefing prior to match play were included in the information packs sent to 46 teams competing in the surveyed rugby tournaments. Over the five tournaments, 42 teams were represented by an EFA at the briefings. Following the briefing, EFA's were approached to participate in a short, structured interview regarding head injuries in rugby union. Individuals acting as designated EFA's that held a primary Team Coach role (n=2) were excluded from the study. This aligns to RFU guidance that advises EFA roles to be solely dedicated.(444) No EFA's who were approached refused to participate with all providing audio and written consent. Institutional ethics approval was obtained for the study and rugby club site permission was granted.

### 4.3.2 Participants

Forty EFA's agreed to participate and were invited to answer a series of brief questions

(3-4 minutes) regarding their thoughts and understanding around concussion. Responses were audio recorded with participant permission. All EFA's were informed that participation was voluntary and confidential, with their data coded to allow permission withdrawal at any point.

### 4.3.3 Interview

During the course of the event, two researchers approached EFA's away from active games and gained consent to participate via the signing of a study information sheet. The researchers asked each EFA a series of structured questions with their audio responses recorded on a smart phone. (see Appendix A) The interview was divided into two sections. Section One included questions about the EFA age, frequency and nature of their involvement as an EFA, the concussion education they had received, and sources they had used to obtain concussion information. This was followed by a series of structured questions surrounding the EFA perceived role and responsibilities within concussion prevention, identification and treatment. The structured questions were adapted from the socio-technical systems approach employed by Clacy *et al*.(1) (Table 1.) to investigate key stakeholder beliefs in Australian rugby union.(1) A structured face to face interview approach was used over that of mail shot/online data collection to negate the potential for high non-response rates, motivate participants and garner responses that were as honest as possible.(447) The structured nature of the survey limited interviewer bias(447) which allowed multiple researchers to conduct interviews and enable greater participant numbers**.**

Table 4.1 Role-specific questions regarding concussion modified from Clacy *et al*.(1)

| | |
|---|---|
| **Prevention** | In your role, are you involved in preventing concussion?<br>What are your responsibilities in preventing concussion?<br>How would/do you prevent concussion? |
| **Identification** | In your role, are you able to identify a concussion/symptom of concussion?<br>What are your responsibilities in identifying concussion?<br>How would/do you identify a concussion? |
| **Treatment** | In your role, are you involved in treating concussion?<br>What are your responsibilities in treating concussion?<br>How would/do you treat concussion? |

### 4.3.4 Data Analysis

Closed question responses were entered into a survey using the online tool *SurveyMonkey®*. Open-ended responses were transcribed verbatim and analysed using QSR International's NVivo 10 software. The lead researcher coded the responses into common themes(448) within prevention, identification and treatment question sub-groups. A second researcher reviewed the themes generated to ensure their distinction and consistency. Discrepancies were reviewed with reference to the audio and transcribed data and redefined until consensus was achieved. The themes defined were then compared to those developed by Clacy *et al*.(1) to establish a degree of commonality.(1) This would allow cross comparison of results from both studies. No themes were identified that fell outside of this previously established thematic structure.(1)

## 4.4 Results

### 4.4.1 Demographics, Participation and Education

EFA's ranged in age from 21 to 53 years, with a mean age of 42 years (SD 7.8). Of the 40 respondents, the majority were female (32, 80.0%) and 87.2% (35) reported being a parent of a player(s) competing on the day. Despite each of the five tournaments being specific to one age group, EFA's reported regularly supporting age groups ranging from U5's to U18's. Most participants reported weekly EFA rugby attendance (27, 67.5%) with almost all (39, 97.5%) participants acting as EFA's at least bi-monthly. (Figure 4.1)


Figure 4.1 Common characteristics of EFA’s within youth community rugby union.

Although all EFA's reported holding a first aid certificate, only 67.5% described the first aid course they attended as sport or rugby specific. When asked if they had received any concussion specific education, 90.0% (36) said yes, although only 60.0% (24) stated they had completed the RFU DBaH online education module. The majority (36, 90.0%) of EFA's reported that they had received a sufficient amount of concussion education for their role. The small proportion (4, 10.3%) who responded that they had not, cited a lack of rugby specific concussion education, the three-year period mandated before course re-completion, and that the course they attended was not paediatric specific, as reasons for not receiving sufficient education for their role.

Over half (23, 57.5%) of EFA's said they would visit the RFU website to find more information on concussion, whilst only 7.3% (3) suggested they would use a non-targeted web search. The remaining EFA's reported that their first contact would be with a Club or School Physiotherapist or Medic (13, 33%) with only one EFA (1, 2.5%) suggesting they would approach a Coach.

### 4.4.2 Role and Responsibilities

#### 4.4.2.1 Prevention

The majority (n=32, 80.0%) of EFA's reported that they felt they had a role in concussion prevention. When asked to consider their perceived role/responsibilities in preventing concussion, four key themes emerged. Education/raising awareness was the most frequently reported role (n=17, 42.5%) Specifically, this was to educate players (n=9, 22.5%) parents (n=6, 15.0%) and coaches (n=3, 7.5%). Improving player safety gained

33% (n=13) of all responses, with encouraging the coaching of proper tackling technique (n=7, 17.5%), wearing protective headgear (n=4, 10.0%) and encouraging the enforcement of the laws, (n=2 6.0%) within this theme. EFA's more frequently cited suitable removal of injured players (n=4, 10.0%) than the overseeing of safe RTP (n=2, 6%) as a perceived prevention role. This and the awareness of player medical histories (n=2, 6%), formed the least common themes.

#### 4.4.2.2 Identification

All EFA's surveyed felt they were able to accurately identify concussion. When asked what they felt their responsibilities and role in concussion identification was, all EFA's stated that it was to watch for potential injuries during play and make on-field/pitch-side judgment's regarding player fitness to continue. When asked what symptoms they might observe from a concussed player, respondents listed an average of 3.6 symptoms. (Figure 4.2) depicts the symptoms listed from the Concussion Recognition Tool 5th edition (CRT5)(115) and the number of times they were identified by EFAs.

When asked to consider what questions they might ask a player suspected of sustaining concussion, 16 different questions were reported. The most commonly asked questions where "What is your name?" (17) and "Where are you/What venue are we at?" (15). Of the 84 total questions cited, only 18 were Maddocks Questions discussed in section 2.6.3, incorporated into the Sport Concussion Assessment Tool (SCAT) from its inception to the latest edition.(449) EFA's reported asking multiple questions of players, with an average of 3.1 (SD ±0.75) questions asked. No two EFA's reported the same set of questions. Figure 4.3 shows the frequency of the questions asked with Maddocks questions(449) highlighted.

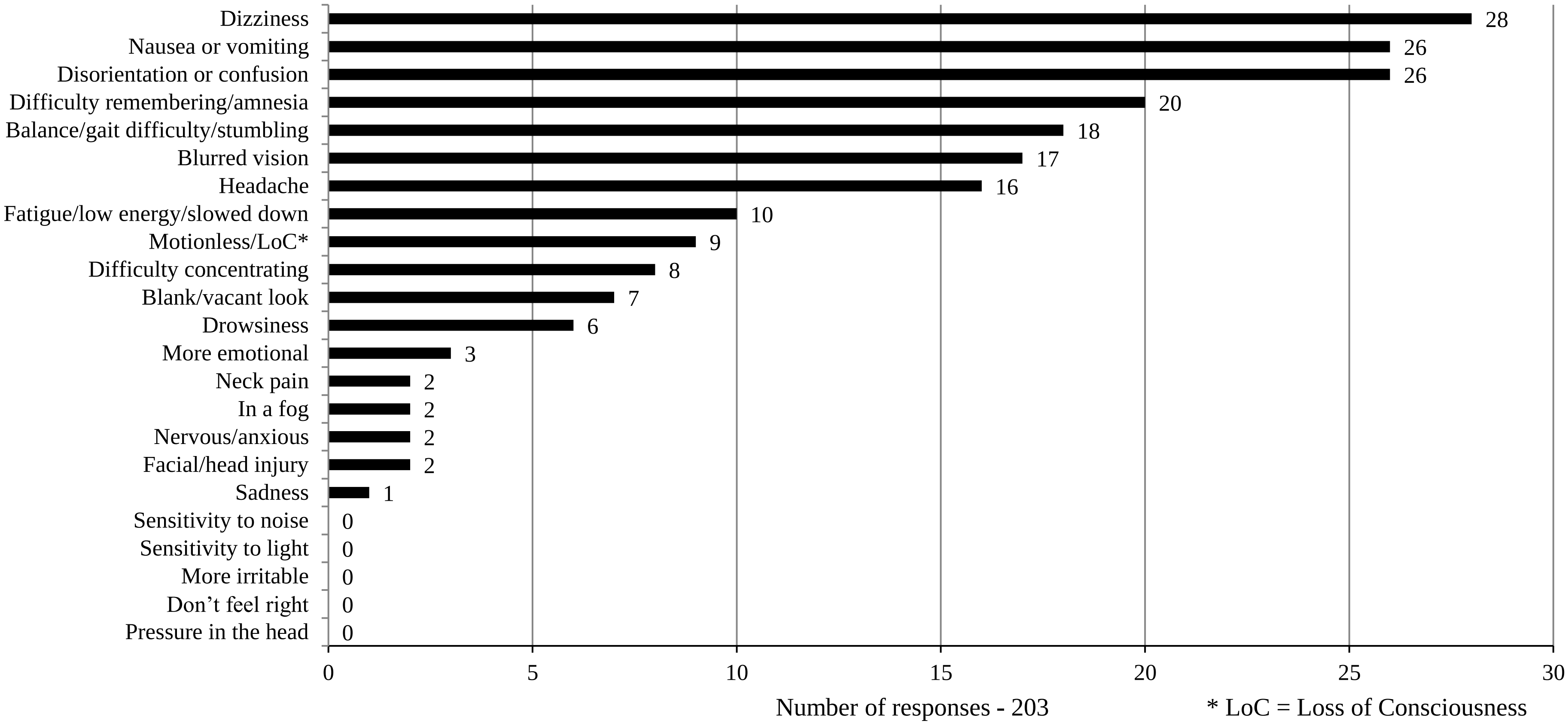


Figure 4.2 Consensus statement signs and symptoms of concussion most frequently identified by youth rugby union Emergency First Aider's (EFA)

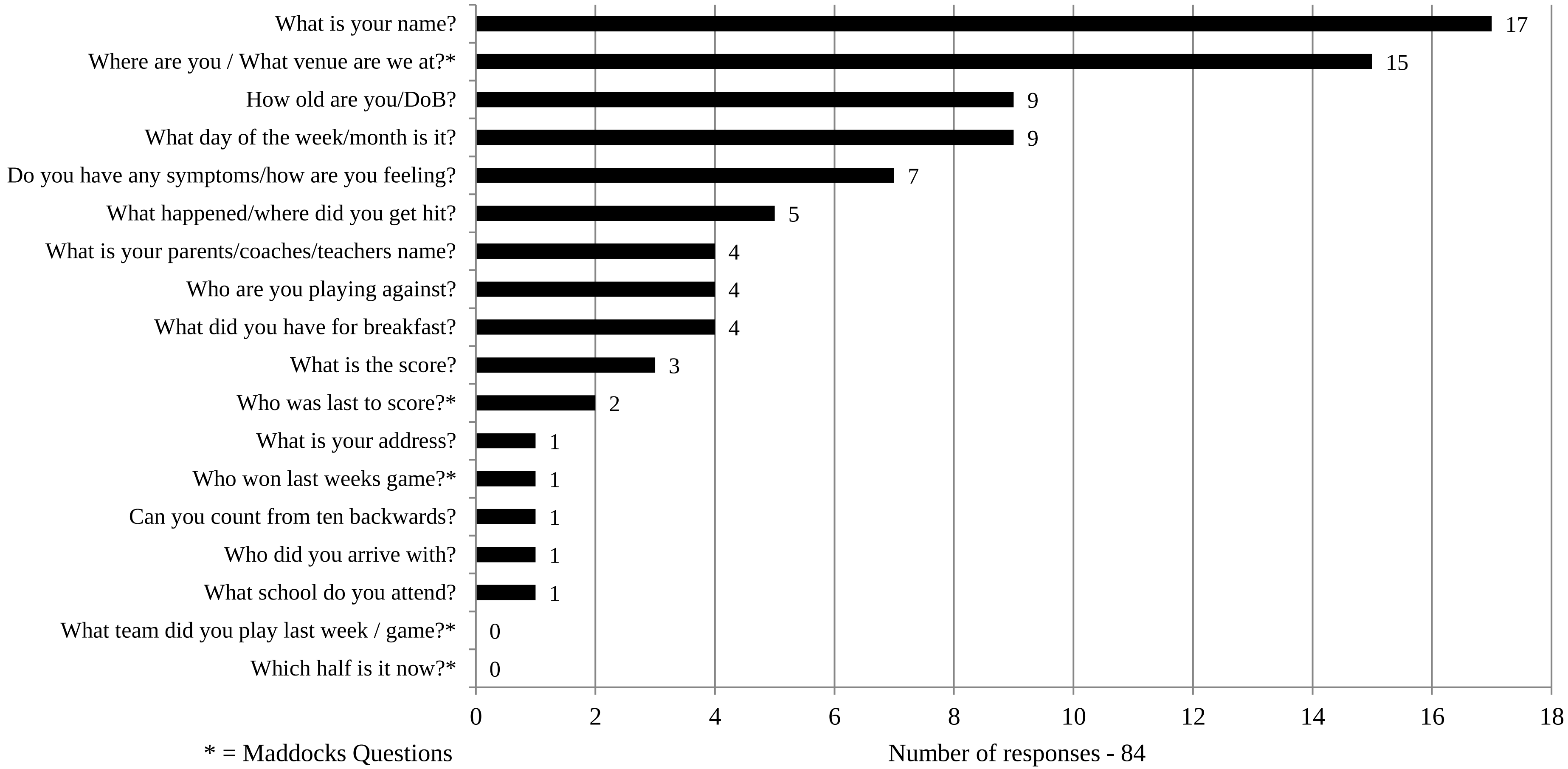


Figure 4.3 Questions most frequently asked by youth rugby union Emergency First Aider's (EFA's) to players suspected of sustaining concussion.

#### 4.4.2.3 Treatment

When EFA's were asked if they felt they had a role in treating concussion, 72.5% (n=29) said yes whilst 11 (27.5%) felt they were not involved. The cited roles and responsibilities of EFA's fell into seven distinct themes. Figure 4.4 shows the most frequently cited concussion treatment roles and responsibilities reported by EFAs.

When asked what further action they might take if a player was removed from play, 16 (40.0%) EFA's suggested they would contact and/or advise the player's parents of the incident. Referral to a club physiotherapist or medic was suggested by 12 (30.0%) EFA's, whilst only five noted that they would ensure that the player did not RTP that day. Figure 4.5 shows the most frequently cited post assessment actions taken by EFA's.

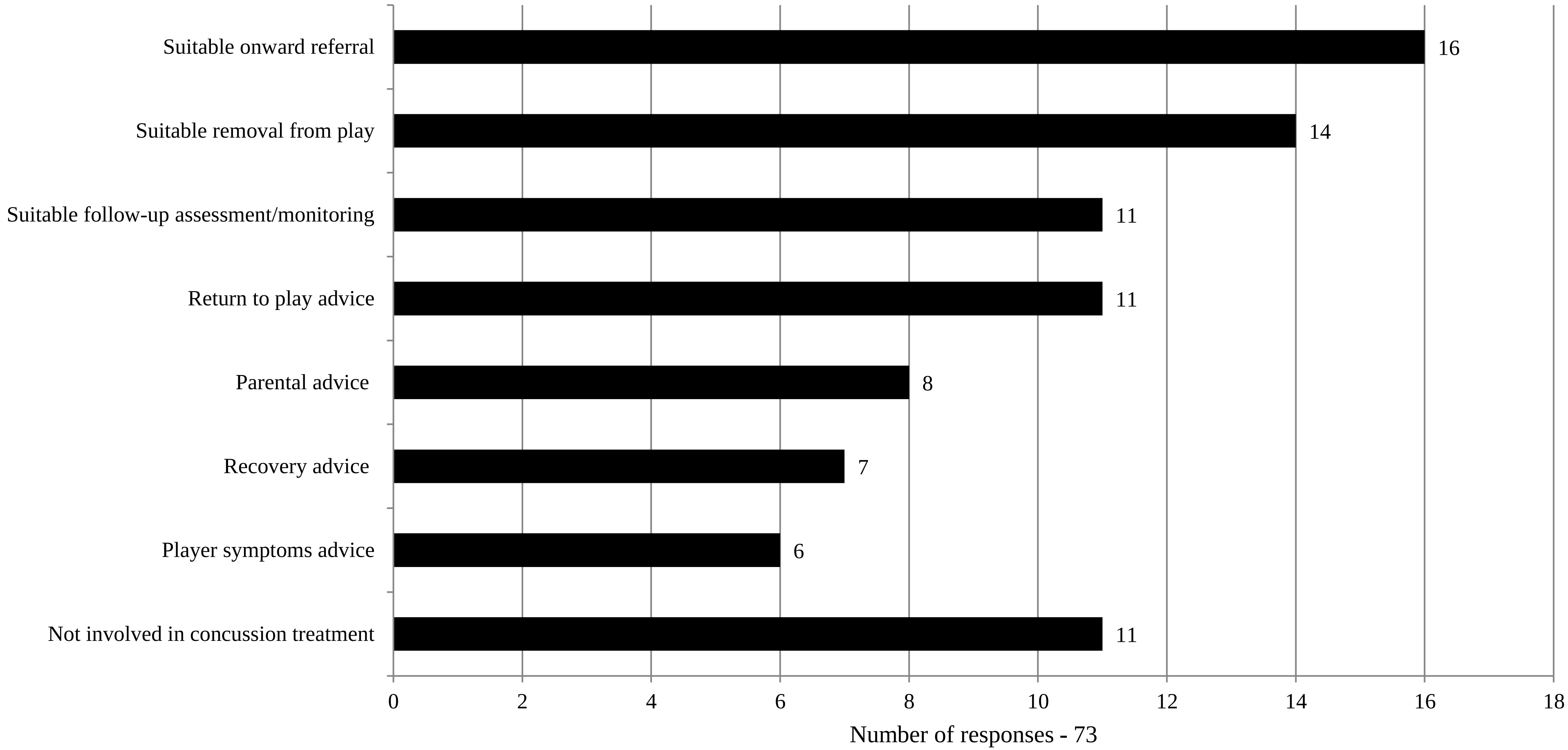


Figure 4.4 The most frequently cited treatment roles/responsibilities of youth rugby union Emergency First Aiders (EFA's)

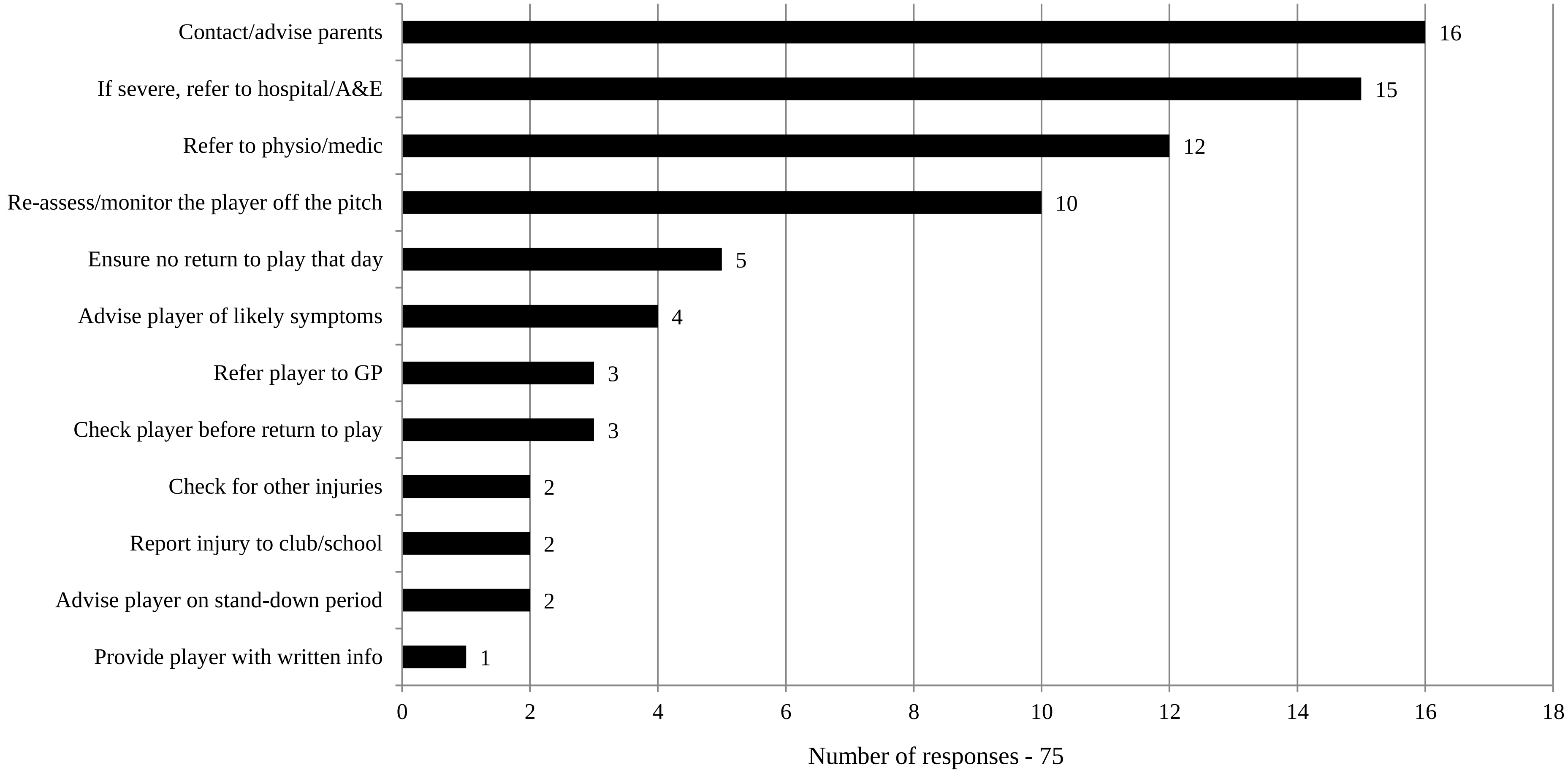


Figure 4.5 Most frequently cited actions taken by youth rugby union Emergency First Aider's (EFA's) following a player's concussion suspected removal from play.

### 4.5 Discussion

This study aimed to implement the socio-technical systems approach employed by Clacy *et al*.(1) to identify the demographic of EFA's within English community youth rugby union and examine their understanding and perceived role/responsibilities of concussion management.

#### 4.5.1 Demographics and Understanding of Concussion Management

Most EFA's were female parents of a playing child, in their 40's, who primarily undertook the role on a weekly basis. This demographic does not align with the number of EFA's registered with the host club. Between 2012 and 2017, 60 EFA's were registered with the host club. This included those whose primary role was coaching and comprised 36 men and 24 women. The results from this study suggest, that despite some coaches holding First Aid registration/qualifications, if teams have designated EFA's in addition to the majority male coaches, it is mothers that commonly perform the role.

A growing body of research has identified differences in concussion attitudes between mothers and fathers. (316)(332)(356) Attitude differences, driven by a range of sociological factors, appear to lead to either more positive or negative attitudes towards risk taking.(39)(450) A parent's degree of drive for perceived sporting achievement appears to underpin such attitudes. Less burdened by perceptions of masculine ideals, women have been cited as demonstrating more positive attitudes towards concussion safety.(325)(332) Within the dominant male playing and coaching demographic of community rugby union, this may imply that a mother's engagement as a EFA is ideal, especially when working alongside mostly male coaching volunteers. For female EFA's whose role success relies on coach and player interaction, understanding how male players and coaches view injury risk taking could enhance the efficacy of their role. This has implications for concussion education. Gender specific EFA and non-volunteer parent education, such as club toilet posters and/or direct member mailshots could enhance knowledge transfer and impart greater attitudinal change,(325) especially when mothers and fathers become more aware of each other's potential attitude bias. The results of this study could be used to direct such interventions. Once educated, EFA's could play a greater role in gender specific parental concussion education. If education becomes an established EFA role/responsibility, EFA's could also be a positive influence on negative attitude/cultural club norms, a factor consistently linked with improving concussion safety.(320)(411)(451)

Greater governing body interaction could mitigate the lack of sport specific concussion understanding observed within the EFA population sampled. This could be achieved through greater engagement with the RFU DBaH online module. Greater governing body engagement could also improve the consistency of concussion education as this was provided by a range of sources. This could account for the disparity in understanding observed. As most sports governing body concussion education has been targeted towards coaches, encouraging greater collaboration, communication and trust between coaches and EFA's could also prove beneficial. As only one EFA reported that a coach would be their first contact for greater concussion information, coaches clearly remain an underutilised resource. With both parties working together towards accurate identification and treatment, player safety would be enhanced. Greater and more consistent concussion education and collaboration may also help address the apparent gap between EFA's perceived lack of further education, and their understanding demonstrated within this study.

### 4.5.2 Perceived Roles and Responsibilities Within Concussion Management

#### 4.5.2.1 Prevention

Within this study, 80% of EFA's perceived they held a role in concussion prevention. This compares similarly to that of coaches (82%), and above that of parents (61%) reported by Clacy *et al.*(1) Despite it being unclear if the parents questioned by Clacy *et al*.(1) had First Aid training, this discrepancy suggests that the role of EFA promotes a greater perception of concussion prevention responsibility over that of a non-volunteer parent. Prevention role themes of EFA's also mirror that of coaches studied by Clacy *et al.*(1) regarding education, player safety and removal from play.(1) This includes the low promoting of protective gear use as a concussion prevention strategy by coaches and medics (6%),(1) echoing that of EFA's within this investigation (9%). These figures sit reassuringly below the 33% of parents that Clacy *et al*.(1) reports, still feel protective gear is a preventative concussion strategy within rugby, an attitude not supported by current research.(365)

Low levels of EFA responsibility for player removal and safe RTP were identified as perceived prevention strategies. When these two aspects are combined into one theme, both this study's EFA's (17%) and the coaches questioned by Clacy *et al.*(1) (18%) show low perceived responsibility for these key preventative actions. Whether these results reflect the respondent's assumption that preventative strategies occur primarily before activity or lack awareness of the dangers of secondary impacts remains to be identified. This result also raises the concern that if EFA's, coaches, and parents do not feel responsible for overseeing safe RTP, who is or should undertake this vital role?

#### 4.5.2.2 Identification

All the EFA's surveyed felt they could accurately identify concussion and that it was their role to do so. High levels of perceived concussion identification across a range of rugby union stakeholders echoes this.(1) This perception is not fully reflected by EFA's recall of concussion symptoms. When asked to state what symptoms they might observe in a player suspected of concussion, on average only 3.6 symptoms were noted. The Concussion Recognition Tool 5th edition (CRT5) lists 20 symptoms of concussion.(115) The most commonly cited symptoms follow the same pattern as has been previously reported,(1)(452) with a bias towards the more physically noticeable symptoms, over behavioural and emotional changes. This may result from EFA's reliance on quickly observable signs over changes that may be more subtle, individual and time dependent. These findings reflect the frequently cited conclusion that key information regarding concussion identification has not yet fully reached athletic coaches,(453) players(369) and parents.(374) As symptom identification forms the cornerstone of successful concussion management, this is concerning. Greater consistency of education, in combination with more practical objective assessment tools, may ensure concussion identification is more consistent.

When asked to report what questions they would ask a player who they suspect has sustained concussion, EFA's reported a variety of questions (n =16), with only 21% of those asked being Maddocks Questions.(30) Such variability in questioning might not be considered problematic if the alternative questions asked adhered to the Maddocks principle of being short-term.(30) This format was built on the premise that information recently acquired is more sensitive to concussive impacts than long-term memory recall.(30)(124) However, the questions asked by EFA's included a mix of long and short-term recall, were subjective in nature e.g. 'how are you feeling?', potentially too challenging e.g. 'what is the score' and where the correct answer was potentially unknown to the EFA, e.g. 'what is your address?' The low number and variability of questions reported suggests that EFA's remain unclear as to what questions to ask a player who they suspect of sustaining concussion. This may have been influenced by the addition of the child specific concussion recognition tool as part of the SCAT3.(277) Despite the greater suitability of the questions for younger children, parents, coaches and EFA's may be unaware of the change or need further support to understand this addition. An updated child specific concussion recognition tool was not published as part of the child SCAT5 in 2017.(277) The use of concussion specific questions remains a key focus for education across all stakeholders.

#### 4.5.2.3 Treatment

Most (73%) EFA's surveyed felt they had a role to play in concussion treatment. This is similar to the previously reported 88% positive responses of medics, and considerably higher than the 25% positive responses of non-EFA parents engaged in community rugby union.(1) If the greatest predictor of behaviour is intent, as described by Ajzen's theory of planned behaviour,(327) such positive role acknowledgement within concussion treatment by EFA's is encouraging. Within this study, intent was demonstrated through EFA's reporting of suitable onward referral and removal from play as their primary treatment roles. This reflects the first aspects of World rugby's 6 R's mnemonic, Recognise, Remove and Refer.(19) Far less emphasis was placed on the following Rest, Recover and Return guidance by the EFA's surveyed. This could be a contributing factor to the poor GRTP compliance commonly observed within community rugby.(10)(44)

As EFA’s appear engaged in the initial aspects of concussion treatment, they may be the best placed stakeholders to address the systemic deficiencies of the current procedures.(1) To achieve this, EFA’s within community rugby require suitable education and encouragement, in addition to support from clubs, governing bodies, parents and players. With enhanced understanding and capabilities EFA’s could be the key to the concussion culture change, particularly safe RTP, sought within Community rugby union.

### 4.6 Limitations

This study was limited by the isolated demographic of the site used. Despite participants being associated with various clubs, all were local to the southern home counties of England. A larger sample across UK clubs may reveal differences in demographic, understanding and perceived roles and responsibilities of EFA’s. Further investigation could highlight the current barriers to suitable GRTP adherence and may help identify how EFA’s can address its management deficiencies.

### 4.7 Conclusion

EFA’s within UK community youth rugby union play a vital role in concussion prevention, identification and treatment. Knowledge of their demographic, understanding and perceived role was previously limited. Most EFA’s were female parents of a playing child, in their 40’s, who primarily undertook the role on a weekly basis. Almost all (80%) EFA’s perceived they held a role in concussion prevention. All EFA’s felt they could accurately identify concussion although this was not fully reflected in symptom recall. The majority of EFA’s felt they played a role in concussion treatment, particularly onward referral. Less perceived engagement within the GRTP process was found. By developing the EFA role from solely first observer/responder, to one that includes promoting individual and social responsibility for symptom disclosure, EFA’s could have a significant impact on stakeholder attitudes and social norms. This could, in turn, increase player safety. This could be achieved by up-skilling EFA’s to lead club-based concussion education to coaches and players, distribute concussion awareness and management materials, and provide a concussion consultancy role to players and coaches. EFA’s could also be a suitable conduit to develop greater shared responsibility between stakeholders and governing bodies. Without stakeholder engagement, governing body risk reduction interventions may lack practical feedback that may enhance their design. Similarly, without stakeholder engagement, the efficacy of intended interventions could be considerably impacted if broad buy-in is not achieved. The knowledge gained from this study could, therefore, help governing bodies to foster greater shared responsibility for concussion injury risk reduction by appreciating and developing EFA’s as a primary link between themselves and players.

# CHAPTER FIVE

## Study Three

**Concussion Knowledge and Attitude of UK Youth Rugby Players: The RUCKAS-YOUTH Survey.**

### 5.0 Overview

Greater understanding of the processes and influences surrounding concussion management obtained from studies One and Two led to the development of Study Three. Study One had exposed the author to many of the challenges of youth concussion assessment and management faced by club stakeholders and parents. In addition to establishing detailed incidence rates and the potential for greater parental engagement, the research highlighted the considerable importance of player symptom disclosure on appropriate management. In addition to enhancing understanding of EFA's and their role, Study Two also spotlighted the responsibility placed on the player for symptom reporting in community-based settings. As a result, Study Three focused on arguably the most influential SRC stakeholder, the players. Many aspects with the potential to influence player engagement in concussion risk reduction remain unclear. Any association between concussion knowledge and attitude in youth rugby players is yet to be established. The influence of school status attendance, sex, age, experience, previous concussion and concussion education, on concussion knowledge and attitude, are also undefined. To address these limitations Study Three employed the novel Rugby Union Concussion and Knowledge Survey (RUCKAS-YOUTH), a platform developed in conjunction with the RFU. It aimed to seek the most comprehensive appreciation of the knowledge and attitudes of UK youth rugby players surrounding concussion to date.

## 5.1 Introduction

Rugby union is a common component of sports provision in schools worldwide.(217) Despite this, rugby union participation amongst 11-16 year old's in the UK has declined since 2014/15.(454)(455) In this time, public concern has grown that the associated risks of injury from rugby may be too high, particularly from sports related concussion (SRC).(217)(425)(443)(456) As SRC can have catastrophic outcomes if not identified or managed appropriately, particularly for young players, injury risks may be a contributing factor to falling engagement and present a distinct and continued threat to sporting participation.(350)

Rugby governing bodies have sought to mitigate injury risks whilst maintaining the core tenants of the game, with a particular focus on SRC. Assessment protocols, law amendments and educational initiatives have been implemented following targeted research.(200)(226)(457)(381)(see section 2.8) A paucity of investigation into the effects of SRC on children and adolescents in rugby(216)(458) has compounded uncertainty. Reported concussion rates at community youth levels have varied greatly and unlike professional grades, have yet to form consensus.(5) Study One within this thesis reported a concussion incidence rate of 12.7/1000 match hours, a figure that represents one of the highest recorded to date.(459) As with this study, youth rugby data commonly details 'reported concussion incidence',(216) not to be conflated with true concussion prevalence. At elite rugby levels, where players receive the scrutiny of cameras, multiple medics and the watching public, less onus falls on the player to disclose symptoms. Concussion prevalence can, therefore, be inferred from the frequency of post assessment diagnoses. At community grades where observable symptoms can go unseen by key stakeholders, player reporting intention becomes a more influential factor.(460) As a result, player knowledge, attitudes, and the social norms of the environment, heavily influence the likelihood of symptom reporting to pitch-side parents, coaches, first aiders, and when present, medical personnel.(38)(39) In addition, this leaves ‘reported incidence’ as the only metric from which to infer prevalence. This is particularly impactful for rugby as young players have the highest participation rates and commonly suffer head injury symptoms longer than young adults.(15) Such reliance on symptom reporting risks non-removal from play, unsuitable recovery and limited injury prevalence understanding.

The lack of reliable youth SRC injury risk data can also lead education-based risk reduction interventions to appear flawed if assessed conventionally.(381) This would commonly be achieved by monitoring injury frequency before and after an intervention.(46) Within SRC, injury reporting may increase following an intervention, a potentially positive outcome, although appearing to demonstrate heightened injury risk. Whilst understanding of youth rugby player SRC knowledge and attitudes is limited, and objective SRC rates remain poorly defined, an alternative means of intervention validation is required. This could be achieved through baseline establishment of SRC knowledge and attitudes that can then be used for post-intervention comparison. Despite the inherent gap between intended and actual behaviour, this may negate the current reliance on observable injury rate change commonly used to validate risk reduction strategies. Armed with an increased understanding of current player SRC knowledge and attitude limitations, governing bodies can then design and implement targeted interventions to enhance player welfare. Several SRC based knowledge and attitude surveys have been developed to this end. A prominent platform has become the validated (345) Rosenbaum Concussion Knowledge and Attitude Survey (RoCKAS-ST) discussed in section 2.7.2.(329) As with other sports, this youth sport concussion survey has been used within rugby to identify gaps in concussion knowledge and attitude.(361)(423) The two rugby-based studies to incorporate the RoCKAS-ST(461) have, however, been of senior rugby stakeholders with the attitude sections unmodified for rugby specificity. Four publications have formed the core evaluation of youth rugby player concussion knowledge and attitude to date. The earliest report was published in 2006 by Sye *et al.*(348) and focused on New Zealand high school rugby players. In addition to demographics, this novel survey study sought an understanding of player concussion knowledge and RTP guidelines, player information sources, and if players felt concussion guidelines were being followed. The findings from 477 male participants revealed limited knowledge of concussion guidelines and poor adherence to RTP protocols. For several years, this study would stand alone within large scale youth rugby concussion knowledge assessment and now forms a reference to the subsequent growth in concussion awareness.(348)

In 2012 Baker *et al.*(43) published a report of the concussion incidence, knowledge and attitudes of 133 under 20 Irish rugby players. The survey was modified from a pilot study developed by Sullivan *et al.*(319) who assessed the concussion knowledge and beliefs of high school rugby players parents. In addition to demographic and concussion incidence data, the survey was the first to specifically explore attitudes towards symptom reporting intention, the perceived role of protective equipment and RTP through yes/no format questions.(43) Despite the acknowledged small sample size, this publication expanded the scope of attitude assessment initiated by Sye *et al.*(348) and has be consistently referenced by following youth concussion assessment. Also within an Irish cohort, Delahunty *et al.*(363) built on previous investigations to further evaluate influences on concussion attitudes. Through a survey modelled in part on the design of Sye *et al*.(348), the report detailed 304 12-18-year-old players (sex unspecified) focusing on perceived youth concussion incidence. Attitudes surrounding how perceived participation importance shaped reporting intention were described, alongside perceived sources of RTP pressure. Although limited in comparison to the attitude assessment of the RoCKAS-ST(461) published four years previously, Delahunty *et al.*(363) was the first rugby-based publication to highlight the important of behaviour change interventions with rugby concussion risk reduction. The paper concluded by stating brief implications the findings held for school-based rugby health.(363) These included a need for greater concussion education for coaches and referees and suggest govening bodies make such education mandatory.(363) The introduction of this practice is currently under review by the RFU. Delahunty *et al.* do not, however, highlight the need for players to also complete mandatory concussion education, currently not a requirment under any rugby governing body.

Most recently, Kearney and See(350) reported the misunderstandings of concussion within an English youth rugby population. The survey drew on designs developed by Sye *et al.*(348) and the RoCKAS-ST(461). As with the RoCKAS-ST(461), the survey was split into knowledge and attitude sections although in an abridged format. The knowledge section contained eight commonly used true or false questions, a symptom recognition multiple choice section, and an open question asking participants to define what concussion is. Unlike the Likert format employed by the RoCKAS-ST(461), the attitude section contained 11 true or false statements. In addition, the survey collected demographic data including concussion experience, how the injury was perceived to have occurred, and the length of time before RTP. The survey was completed by 236 male and 17 female 11-17-year-old club and school rugby players. The study reported limited player knowledge of concussion guidelines and poor adherence to return to play protocols. (see section 2.7.3) This study was the first to report that greater concussion knowledge was not linked to safer concussion attitudes. As a result, Kearney and See stress the need for on-going concussion education that engages players in the development and dissemination of education resources. When published this study represented the only UK specific review of youth rugby concussion attitudes.(350)

Despite the cumulative growth in youth rugby concussion knowledge and attitude detailed above and in section 2.7.2, no recent investigation that reflects current UK rugby governing body concussion education has been published. Despite providing a foundation of understanding, no prior survey of UK youth populations has encompassed both knowledge and attitude aspects in detail, and included large cohorts of both male and female participants. To address this shortfall, this study developed the RUCKAS-YOUTH survey to establish baseline concussion knowledge and attitude data across a UK youth school rugby union playing population. Through primary paired cohorts defined by sex, school academic status and age, and secondary cohorts of rugby experience, exposure to online concussion education and concussion experience, differences in concussion knowledge and attitudes between the cohorts were identified. The results of which could then be used to direct specific requirements of future educational risk reduction interventions. The results can then establish the efficacy of such interventions, defined as essential by injury risk reduction frameworks(6), if used as a pre-intervention baseline.

## 5.2 Methods

### 5.2.1 Recruitment

Approval was obtained from the St. Mary's University Ethics board prior to conduction. Rugby playing schools actively supported by the RFU were informed of the study via RFU newsletter during September 2019 and following direct email approach to teaching/coaching staff. Study advertisement and recruitment strategies were targeted to achieve as much variation in location, school funding status and playing level/ability as possible. Teaching/coaching staff distributed survey booklets including study information to all players engaged in competitive Rugby aged between 14 and 18 years. Email information and consent documents were sent to parents of under 18 players. The email contained links to opt-in online consent declaration and study withdrawal pages that could be accessed before study completion.

### 5.2.2 Participants

Five hundred and thirty-four 14-18-year-old competitive rugby playing students from 19 English schools provided signed consent and completed the survey booklet between 2019-2022. Participant consent was obtained in writing on the survey booklet and then matched with parental consent prior to data analysis. Seven participant data omissions due to non-parental consent occurred. Participants that failed to complete the survey in its entirety were excluded (n=12). Five hundred and fifteen participants met both consent and completion criteria. Participants were fairly evenly split between private school attendance (n=242), and state school attendance (n=273). The schools were predominantly distributed within the home counties of England including schools from Yorkshire, the Midlands and South Coast.

### 5.2.3 Data Collection

#### 5.2.3.1 The Survey

The RUCKAS-YOUTH Survey was designed specifically for the purposes of this study and included questions from previously developed concussion surveys (either verbatim or modified), in addition to novel components, to facilitate participant comprehension and rugby specificity.(43)(329)(339)(348)(350)(371) The RUCKAS-YOUTH survey is split into three sections. Section One includes participant sex, rugby playing experience, previous concussion history, and sources of concussion education, including whether or not participants had completed the RFU 'Don't Be a HEADCASE' (DBaH) online education module, and if so, when. Section Two (Q7-12) explores concussion knowledge, utilising questions from the youth rugby surveys of Kearney and See(350) from UK cohorts, from Baker *et al.*(43) of under 20 rugby players in Ireland, and youth New Zealand players by Sye *et al*.(348).This section is comprised of two single questions, a question including a series of statements requiring true or false responses, and three multiple choice questions surrounding concussion recognition, concussion complications and appreciation of concussion signs and symptoms. The questions were designed to reflect those used in the aforementioned studies for comparison, and to reflect current RFU concussion education content.(393) Within the True or False section, two Validity Scale (VS) questions modified from the RoCKAS-ST were incorporated.(329) As with the RoCKAS-ST, the questions were included to increase the likelihood of valid responses by assessing participant thoughtfulness and attention to the questions. As such, the VS questions formed part of the exclusion criteria. Participants data was removed if both VS questions were incorrectly answered. All participants answered at least one VS question correctly.

Section Three is based on the format of the RoCKAS-ST(329) and explores eight themes of concussion attitude: Prevention Strategies, Reporting Consequences, Reporting Triggers and Reporting Norms, Return to Play (RTP) Timing, Coach lead RTP, Physio lead RTP intention, and Pressure to Play. (Q13-17) Each theme asks participants to rate their level of agreement to statements or scenarios through a five-point Likert Scale response from 'Strongly Agree' to 'Strongly Disagree'. The concussion scenario statements from the RoCKAS-ST were utilised as a starting point, and then modified into rugby specific contexts, e.g.

> *"Athlete H suffered a concussion and has a game in two hours. He is still experiencing symptoms of a concussion. However, athlete H knows that if he tells his coach about the symptoms, his coach will keep him out of the game."*

Modified to:

> *"A Rugby Sevens player experienced a concussion and has a game later in the day. They are still experiencing symptoms of concussion., However, the player knows that if he tells his Coach about the symptoms, his Coach will keep him out of the game."*

In addition, following the amendments made by Kroshus *et al.*(371) to the original RoCKAS-ST, attitude statement prefixes were altered from *"I would…"* and *"Most athletes would…"* to *"My teammates would…"* and *"Most athletes would…".* Kroshus *et al.*(371) cite these modifications to separately reference athlete norms and teammate norms, a distinction less clear within the original format.(371)  Within the RUCKAS-YOUTH survey, "athletes" was also exchanged with "players" to adopt rugby vernacular. The novel component of the attitude section surrounding Pressure to Play was developed by the authors in collaboration with an RFU medical research group. This section was designed to identify possible influences on participation choices that may be experienced following head injury. The working group reviewed the survey in its entirety before data collection commenced.

A pilot review of the survey comprising three female and seven male community rugby club participants aged 15.8 ±1.5 years was conducted prior to study launch. The pilot established the average survey completion time of between 10-12 minutes and led to the changing of 'locker room' to changing room" in question 9e and 'Cleats' to 'Studs' in the VS scale question 8g, following participant queries.

### 5.2.4 Data Handling

Paper based survey responses were manually entered onto JISC online survey (JISC 2020) by the lead researcher/author and exported to Microsoft Excel and IBM SPSS Statistics 28 (2021) for analysis. A result was considered significant if $p < 0.05$. Established from section one answers, primary cohort groups were defined by sex, private or state school status and age group (14-16 years and 17-18 years) (table 1). Secondary cohort groups of participants who had, and had not completed the DBaH online module were defined, in addition to previous concussion history (no previous history, one previous concussion, two previous concussions, ≥ 3 concussions) and rugby experience (≤ 6 years' experience and 7-15 years' experience). Questions from both concussion knowledge and attitude sections were grouped into themes. Themes were established around the key features of concussion management established within the current RFU concussion education programme(393) such as 'Prevention Strategies' and 'Concussion Complications'. The themes also reflect those used within the concussion knowledge and attitude indices framework established by the RoCKAS-ST.(329) Cronbach α scores were calculated to assess concussion attitude theme internal consistency with Cronbach α scores of >0.7 considered acceptable.(462) A participants Concussion Knowledge Index (CKI) was defined by the number of correct answers to each knowledge question which scored one point (maximum score available 33). Overall and cohort mean ± SD CKI scores are presented alongside mean scores as a percentage of correct answers. For concussion attitude indices, responses deemed the safest attitude scored five, with the least safe scoring one. Where appropriate, questions were reverse coded to convert initial numerical inferiority. Attitude scores ranged from 34-170 and were reported as a percentage of the safest score alongside mean ± SD. Participant knowledge question scores are defined on a spectrum of correct/incorrect and lower to higher. Responses to concussion attitude statements answered in

Likert format are defined on a spectrum of attitude safety, the higher the score between 1-5, the safer the attitude. 5/5 or 100% represents the safest achievable attitude.

**5.2.5 Data analysis**

Differences in individual knowledge question responses within paired cohort groups (male v female, state v private, upper v lower age), were assessed with independent samples t-tests. Differences between individual CKI and CAI scores divided by cohort were assessed with Mann-Whitney U tests as data was considered ordinal in nature. Cohort associations between knowledge and attitude indices variables were established through Pearson's tests as the variables were considered continuous in nature. Differences in mirrored statements within the attitude sections separated by 'Most players', a reference to personal attitudes, and 'My teammates', a reference to perceived social norms (329)(423)(371) were established with Independent Samples t-tests. Ordinal Logistic Regression was used to assess the predictive influence of any CKI themes and theme questions that demonstrated individual association with CAI scores.

**5.3 Results**

**5.3.1 Demographic Information**

Male participants represented 81.7% of the surveyed population with females 18.3%. (table 1) Participants were split between 53% State school and 47% Private school attendance. Three hundred participants (58.3%) had ≤ six years of rugby playing experience whereas 215 (41.7%) had played for between seven and fifteen years. The majority of participants (83.1%) stated that they had not completed the RFU DBaH online module before. Private school attending participants (23.1%) reported significantly higher DBaH completion than state school counterparts. (11.4%) $t(376) = 3.6$ $p=0.0003$.) Of the 441 (85.6%) of participants who reported receiving education/guidelines from another source, 64.2% cited a school teacher/coach whilst only 9.3% of participants citing it coming from a physiotherapist (See table 2). Over half of the participants (52.8%) reported that they had not received a concussion in the past. Of those that had, 22.3% stated it being once, 12.8% stated twice, and 12.0% three times or more.

Table 5.1 Participant demographics, concussion history and concussion education

| | Female | Male | State | Private | 17-18 | 14-16 | Total |
|---|---|---|---|---|---|---|---|
| **All** | **94 (18.3%)** | **421 (81.7%)** | **273 (53.0%)** | **242 (47.0%)** | **113 (21.9%)** | **402 (78.1%)** | **515** |
| **Female** | | | 82 (87.2%) | 12 (12.8%) | 16 (17.0%) | 78 (83.0%) | **94 (18.3%)** |
| **Male** | | | 191 (45.4%) | 230 (54.6%) | 97 (85.8%) | 324 (77.0%) | **421 (81.7%)** |
| **Rugby experience (years)** | | | | | | | |
| 0-3 | 56 (59.5%) | 118 (28.0%) | 138 (50.5%) | 36 (14.9%) | 11 (9.7%) | 163 (40.5%) | **174 (33.8%)** |
| 4-6 | 28 (29.7%) | 98 (23.3%) | 62 (22.7%) | 64 (26.4%) | 25 (22.2%) | 101 (25.1%) | **126 (24.5%)** |
| 7-9 | 9 (9.6%) | 106 (25.2%) | 40 (14.7%) | 75 (31.0%) | 25 (22.1%) | 90 (22.4%) | **115 (22.3%)** |
| 10-12 | 1 (1.1%) | 80 (19.0%) | 24 (8.8%) | 57 (23.6%) | 33 (29.2%) | 48 (11.9%) | **81 (15.7%)** |
| 13-15 | - | 19 (4.5%) | 9 (3.3%) | 10 (4.1%) | 19 (16.8%) | - | **19 (3.7%)** |
| ***'Don't Be a HEADCASE'* online module completion** | | | | | | | |
| | 15 (16.0%) | 72 (17.1%) | 31 (11.4%) | 56 (23.1%) | 35 (31.0%) | 51 (12.7%) | **87 (16.9%)** |
| **Timing of completion** | | | | | | | |
| | **n=15** | **n=72** | **n=31** | **n=55** | **n=35** | **n=51** | **n=87** |
| This year/season | 5 (33.3%) | 32 (44.4%) | 11 (35.5%) | 25 (45.4%) | 13 (37.1%) | 23 (45.1%) | **26 (29.9%)** |
| Last year/season | 7 (46.7%) | 27 (37.5%) | 13 (42.0%) | 21 (38.2%) | 15 (42.9%) | 19 (37.3%) | **46 (52.9%)** |
| 2 years/seasons ago | 3 (20.0%) | 13 (18.1%) | 7 (22.5%) | 9 (16.4%) | 7 (20.0%) | 9 (17.6%) | **15 (17.2%)** |
| **Previous concussion history** | | | | | | | |
| No | 71 (75.5%) | 201 (47.7%) | 156 (57.4%) | 116 (42.6%) | 34 (12.5%) | 238 (87.5%) | **272 (52.9%)** |
| Yes, once | 13 (13.8%) | 102 (24.2%) | 66 (57.4%) | 49 (42.6%) | 32 (27.8%) | 83 (72.2%) | **115 (22.3%)** |
| Yes, twice | 4 (4.3%) | 62 (14.7%) | 23 (34.8%) | 43 (65.2%) | 21 (31.8%) | 45 (68.2%) | **66 (12.8%)** |
| Yes, three times or more | 6 (9.7%) | 56 (13.3%) | 28 (45.2%) | 34 (54.8%) | 26 (41.9%) | 36 (58.1%) | **62 (12.0%)** |

Table 5.2 Concussion education/guideline sources by sex, school type and age group

| | **Female**<br>**n=67** | **Male**<br>**n=374** | **Private**<br>**n=215** | **State**<br>**n=226** | **17-18**<br>**n=102** | **14-16**<br>**n=339** | **All**<br>**N=441 (85.6%)** |
|---|---|---|---|---|---|---|---|
| School Teacher/Coaches | 27 (40.3%) | 255 (68.2%) | 170 (79.1%) | 113 (50.0%) | 67 (65.7%) | 216 (63.7%) | **283 (64.2%)** |
| Rugby Club Coach | 38 (56.7%) | 181 (48.4%) | 103 (47.9%) | 117 (51.8%) | 72 (70.6%) | 148 (43.7%) | **220 (49.9%)** |
| Parents | 25 (37.3%) | 138 (36.9%) | 83 (38.6%) | 88 (38.9%) | 43 (42.2%) | 128 (37.8%) | **171 (38.8%)** |
| Friend/Teammate | 12 (17.9%) | 80 (21.4%) | 55 (25.6%) | 37 (16.4%) | 32 (31.4%) | 60 (17.7%) | **92 (20.9%)** |
| School Nurse or Medical Staff | 1 (1.5%) | 93 (24.9%) | 67 (31.2%) | 23 (10.2%) | 33 (32.4%) | 57 (16.8%) | **90 (20.4%)** |
| Seen on TV/Social Media | 7(10.4%) | 83 (22.2%) | 42 (19.5%) | 47 (20.8%) | 29 (28.4%) | 60 (17.7%) | **89 (20.2%)** |
| Doctor | 6 (9.0%) | 94 (25.1%) | 56 (26.0%) | 32 (14.2%) | 33 (32.4%) | 55 (16.2%) | **88 (20.0%)** |
| Physiotherapist | 4 (6.0%) | 38 (10.2%) | 29 (13.5%) | 12 (5.3%) | 12 (11.8%) | 29 (8.5%) | **41 (9.3%)** |

### 5.3.2 Concussion Knowledge Index

The overall mean concussion knowledge index was 26.2 ± 2.9 (out of a possible 33), representing a mean correct response rate of 79.3%. No significant differences were observed in mean CKI scores between primary or secondary cohorts (Figure 5.1)

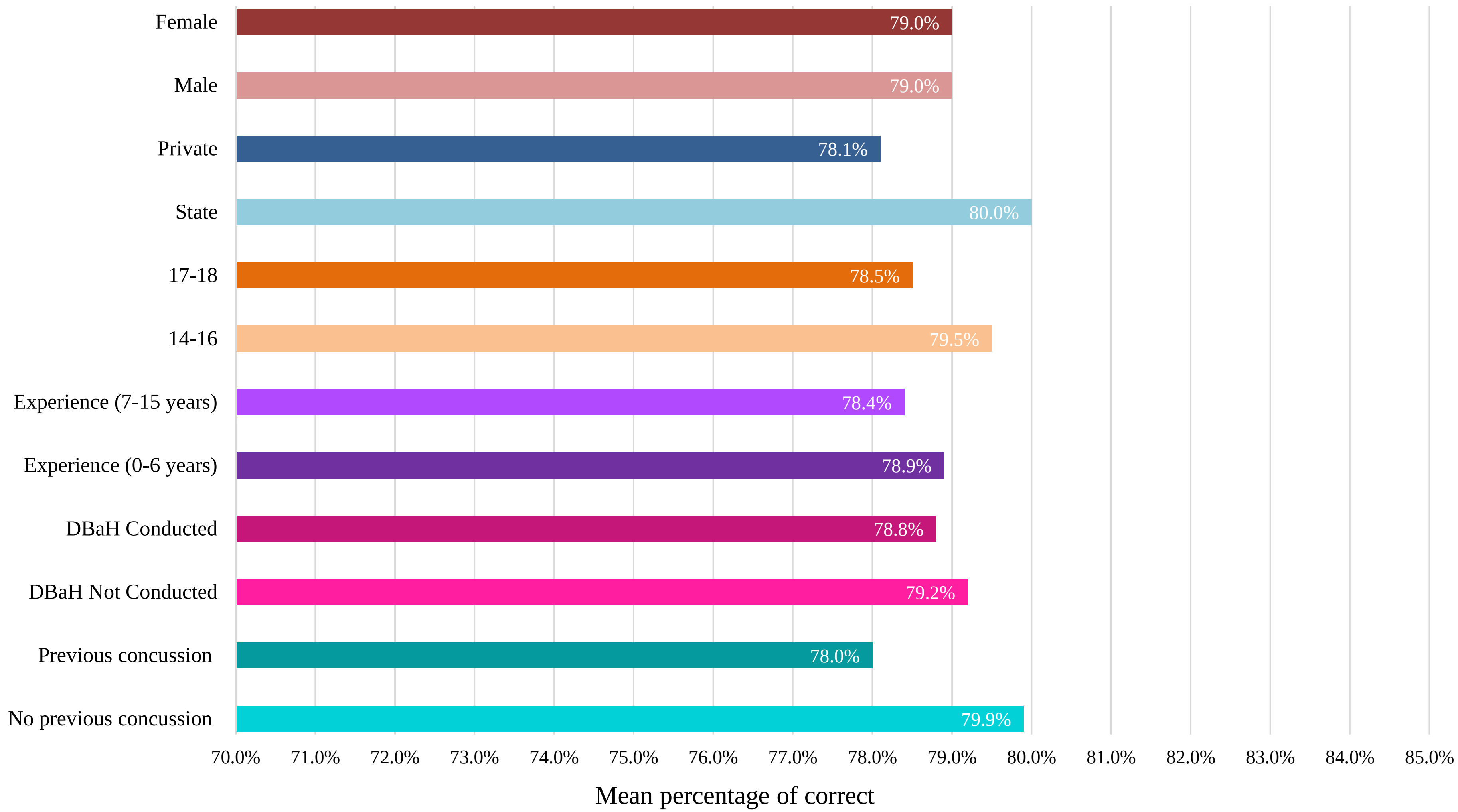


Figure 5.1 Mean CKI as a percentage of correct answers by cohort group

### 5.3.3 Concussion Knowledge Themes

Figure 5.2 shows the cohort mean scores as a percentage of correct for each concussion knowledge theme. Overall, participants scored an average of 3.6 ± 0.8 out of 4 correct answers (89.6%) within the 'Symptom Recognition' theme, achieving the highest knowledge theme score (Figure 5.3). No significant differences were observed between the cohorts. From a total list of 18 'Signs and Symptoms' of concussion, participants correctly recognised an average of 6.6 ± 1.3 from eight defined within the SCAT5.(116) This represents an average 82.5% recognition rate, with the symptoms 'Blurred Vision' (67.6% ± 0.2), 'Headache' (67.4% ± 0.2) and 'Confusion' (65.4% ± 0.2) most frequently recognised (Figure 5.4) Despite appearing so, no significant difference in this themes scores was observed between participants that had, and had not completed the DBaH online module ($t(513)=0.60$ $p=.551$). The 'True or False' theme held a mean correct score of 9.4 from 13 answers representing an 80.0% ± 0.2 accuracy rate (Figure 5.5). The ranking of individual True or False questions are displayed in Figure 9 below. The possible 'Complications' that might be experienced after sustaining a second head injury whilst still recovering from concussion, were identified through eight potential post-concussion consequences (Figure 5.6) Participants correctly identified an average of 4.6 ± 1.5 from six correct outcomes with a mean correct score of 76.8% ± 1.5. Two single questions complete the concussion knowledge themes. Figure 5.7 shows the cohort responses to the question, "How long is the recommended minimum relative rest period following concussion for both adults and youth rugby players, before a graded return to play can start?" (Correct Answer – 14 Days). Overall, 55.5% ± 0.5 of participants answered this question correctly, stating "14 Days". Figure 5.8 shows the cohort responses to the question, "Who is recommended to perform a medical review/assessment of a player before a return to contact-based rugby flowing concussion?" Overall, 49.3% ± 0.6 correctly stated "GP/Doctor".

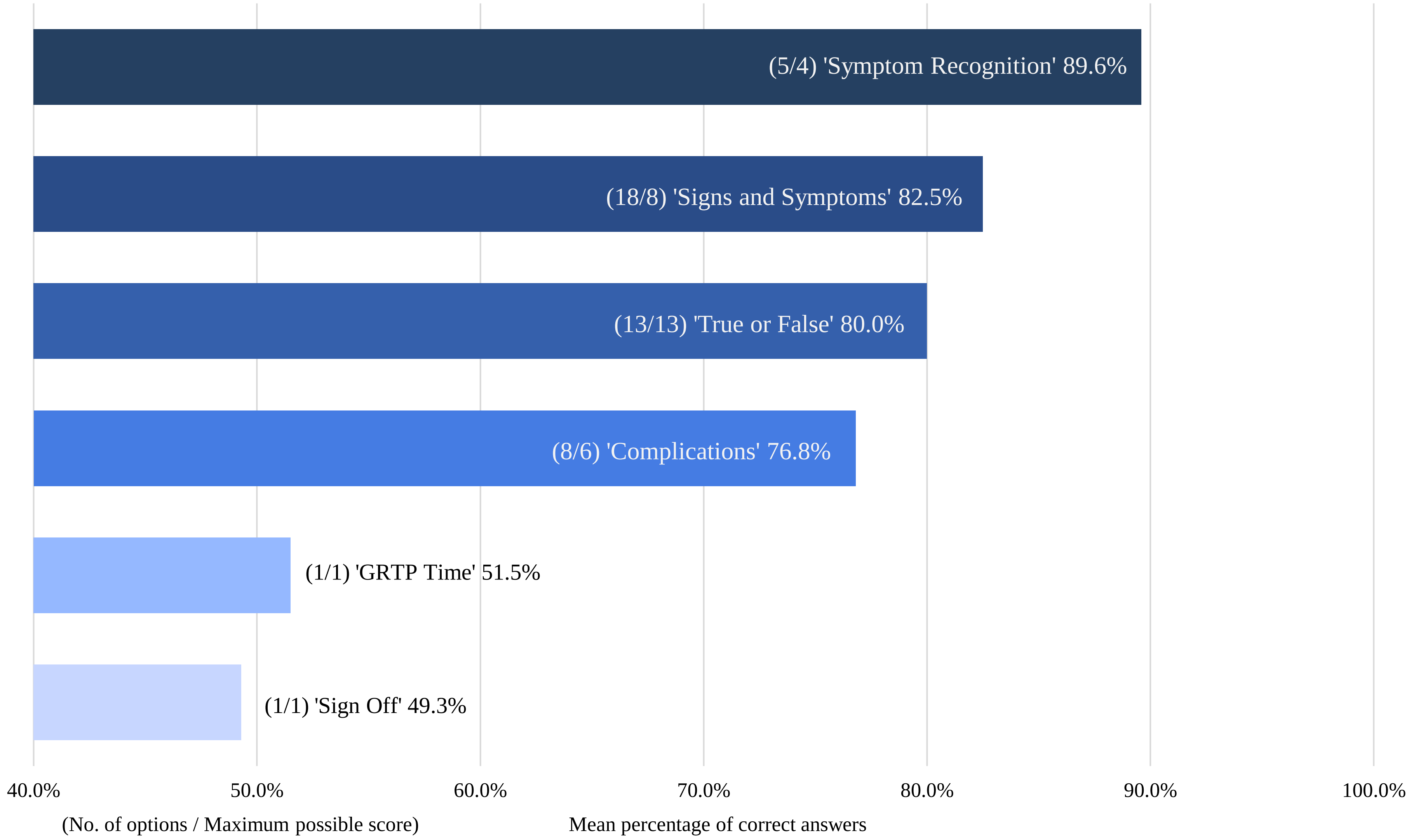


Figure 5.2 Overall mean concussion knowledge theme scores as a percentage of correct

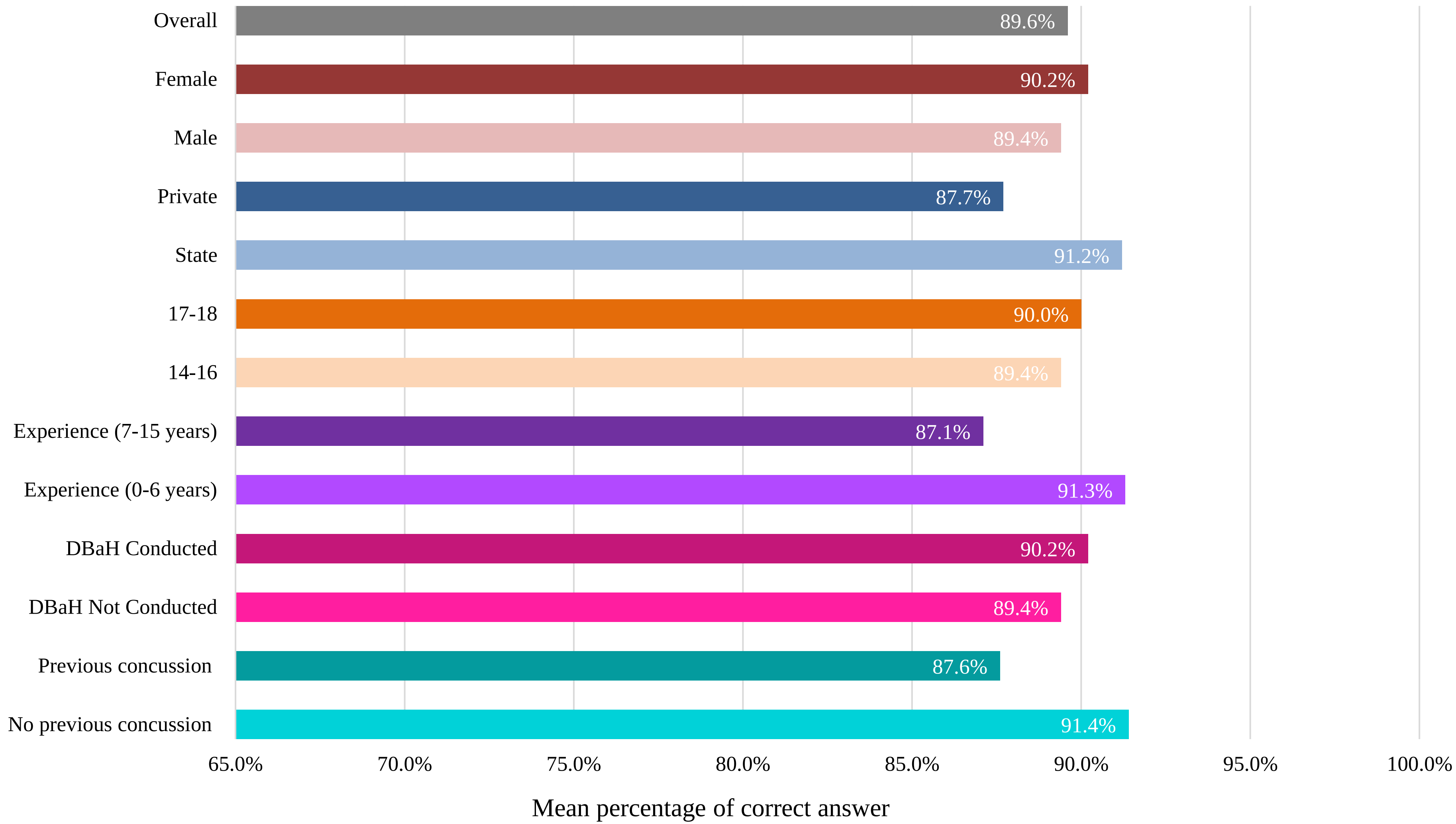


Figure 5.3 Mean percentage 'Symptom Recognition' theme scores by cohort

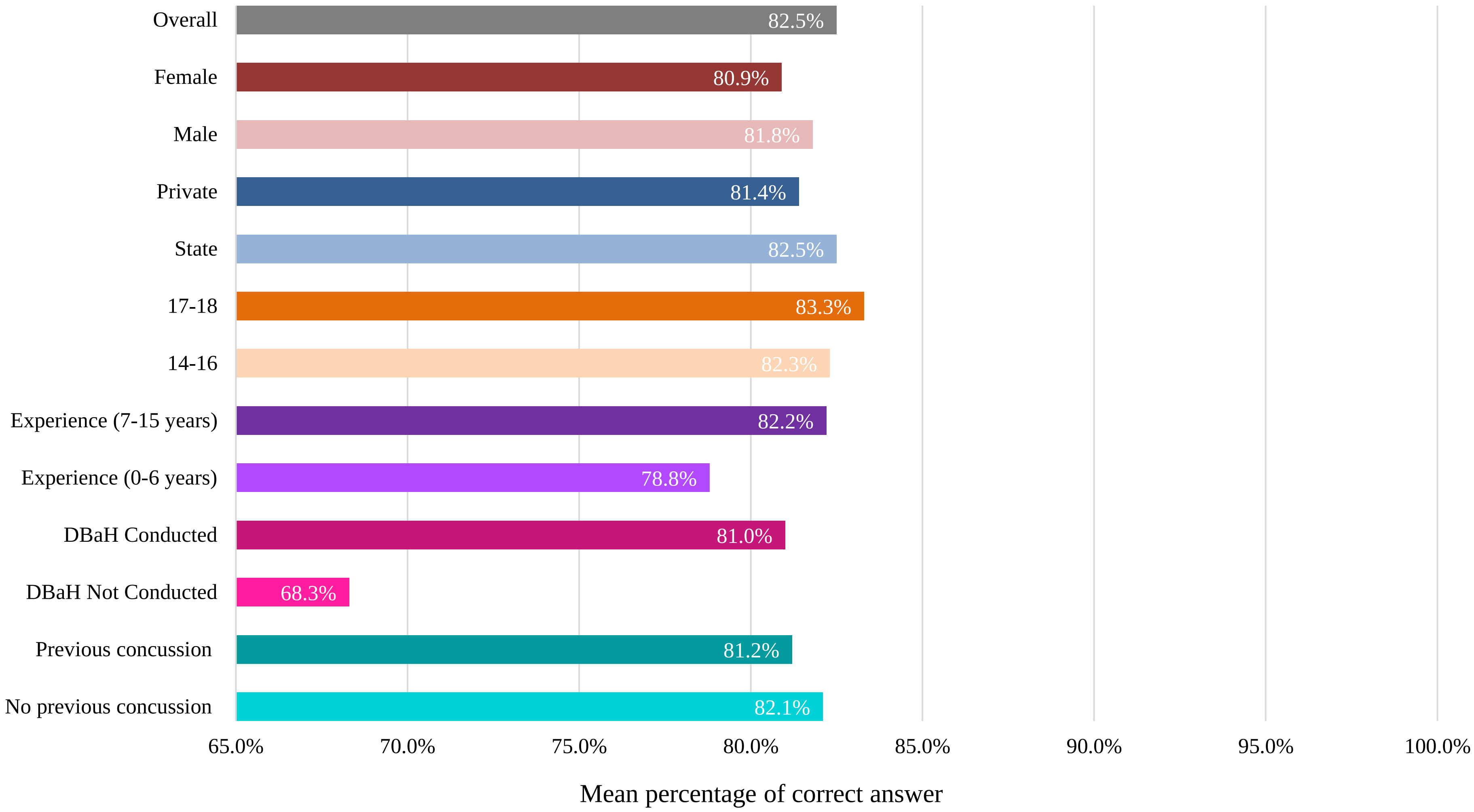


Figure 5.4 Mean percentage 'Signs and Symptoms' theme scores by cohort

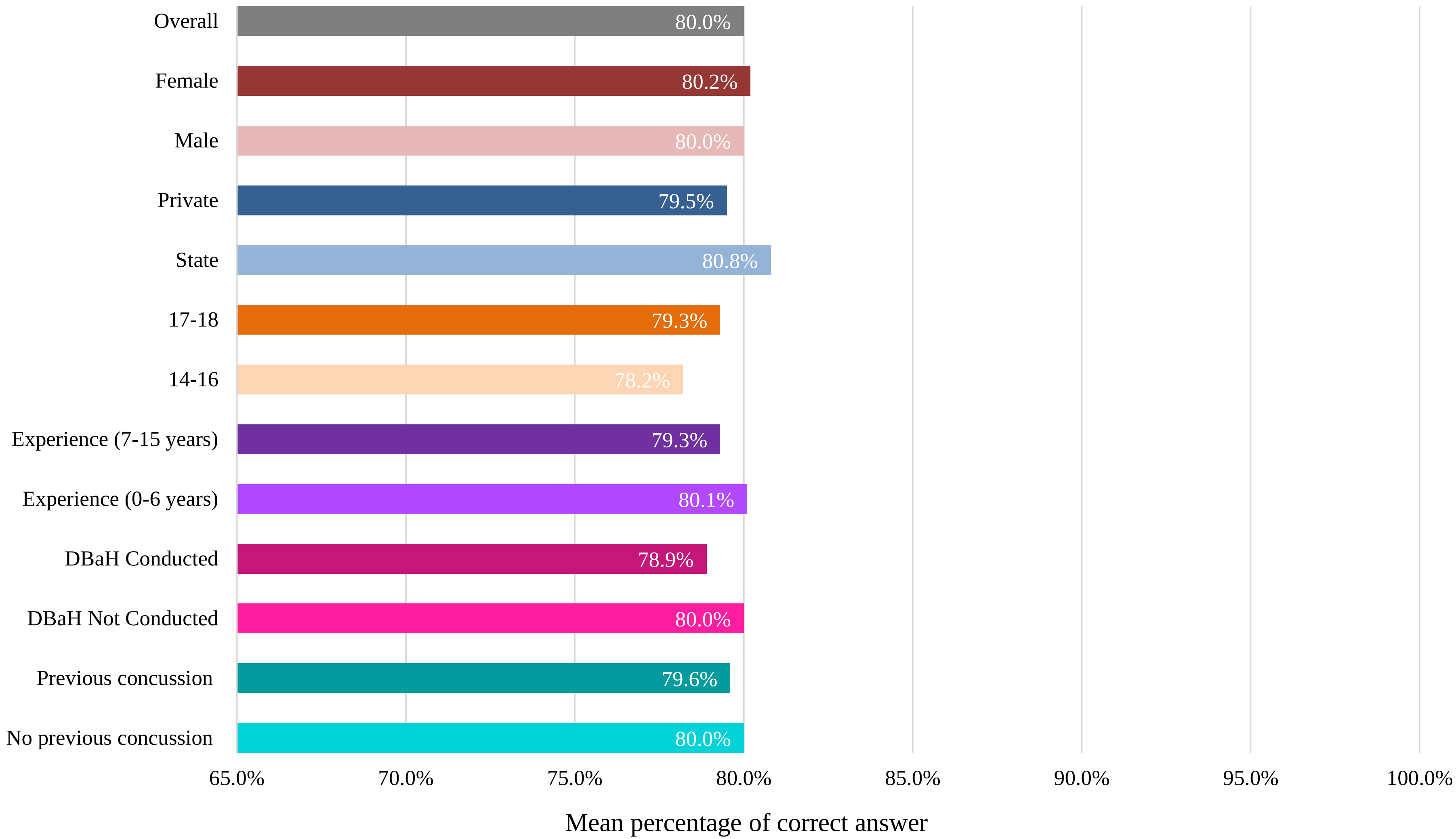


Figure 5.5 Mean percentage 'True or False' theme scores by cohort

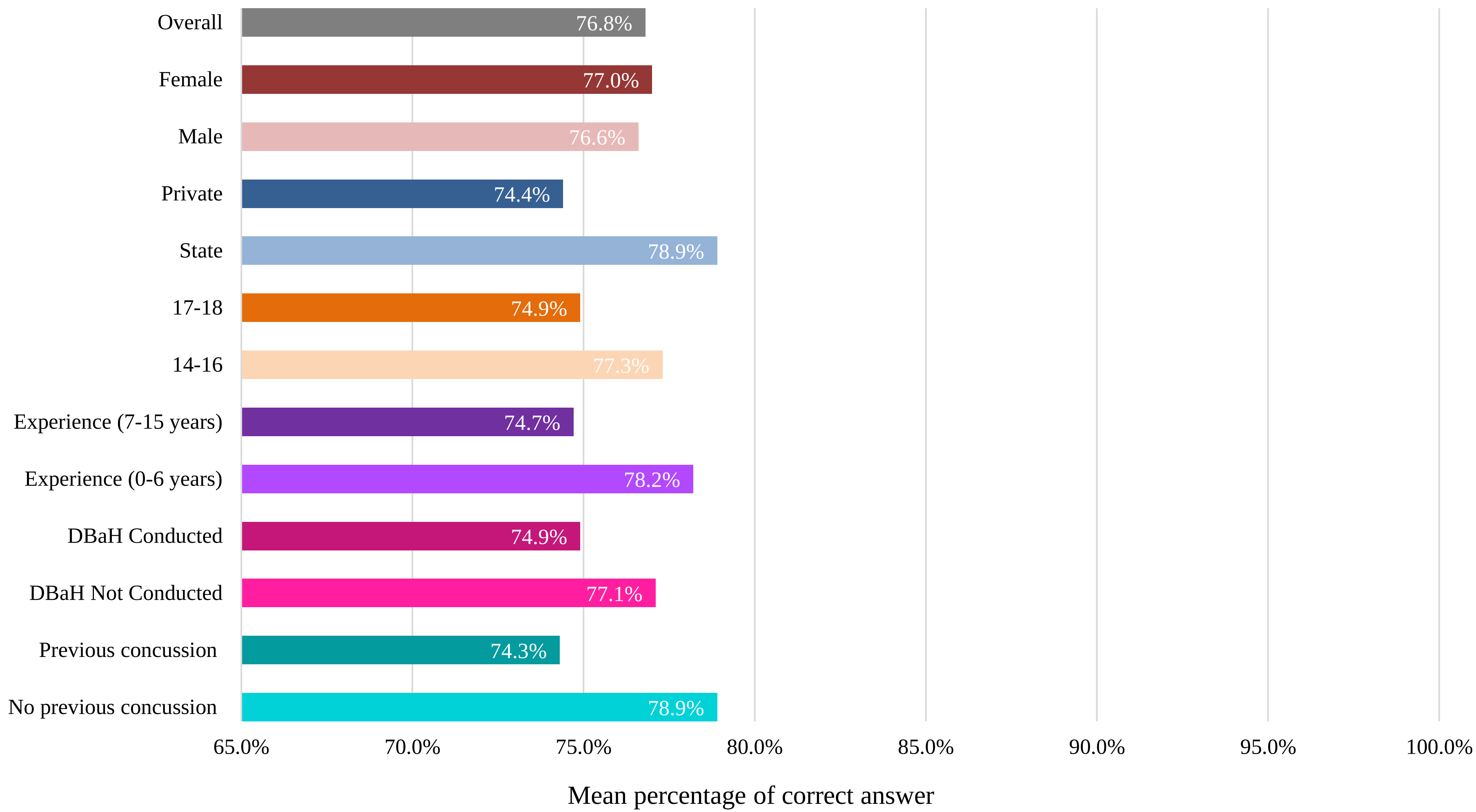


Figure 5.6 Mean percentage 'Complications' theme scores by cohort

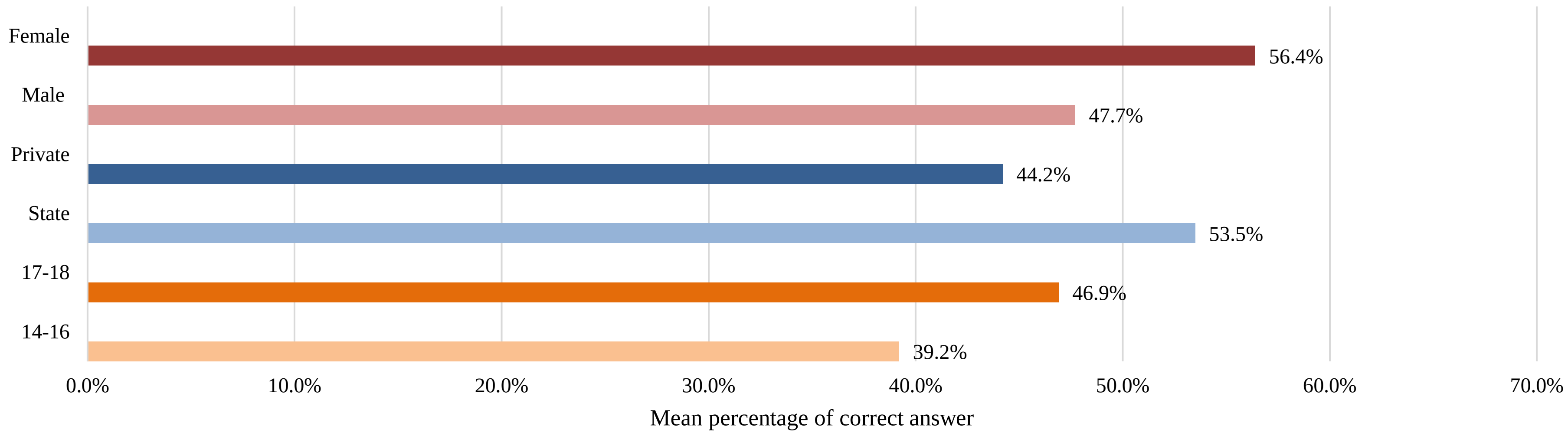


Figure 5.7 Percentage of correct answers to ‘How long is the recommended **minimum relative rest period** following concussion for both adults and youth rugby players, before a graded return to play can start?’ by cohort. **(Correct Answer – 14 Days)**

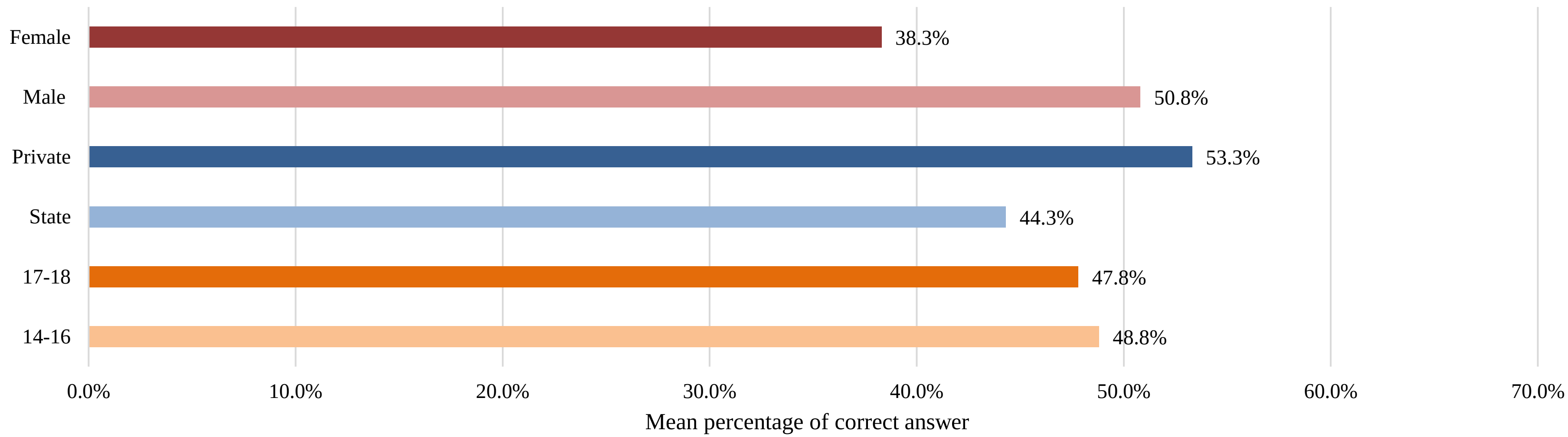


Figure 5.8 Percentage of correct answers to ‘Who is recommended to perform a **medical review/assessment** of a player before a return to contact-based rugby flowing concussion?’ by cohort **(Correct Answer – GP/Doctor)**

### 5.3.4 Concussion Knowledge Questions

Figure 5.9 displays the overall mean percentage of correct scores for each concussion knowledge question. Almost all (96.3%) participants correctly stated that 'You do not need to be 'knocked unconscious' to be concussed', whilst only 41.9% answered correctly that the statement 'Concussions can only occur from a hit to the head' was false. The True or False theme contained 12 unrelated SRC questions. Five questions were answered correctly by over 90% of participants, including 'You have to be knocked out to be concussed (False)' (96.3%), 'Although symptoms may resolve quickly, the brain may not have fully recovered after concussion' (95.9%) and 'concussion is as serious as other injuries' (94.8%). Three questions were answered correctly by less than half of participants. 'Concussion can only occur from a hit to the head' (41.9%), 'After ten days of symptoms concussions are usually gone' (45.2%) and 'Young people are at greater risk of concussion than adults' (46.6%). The question, 'There is a possible risk of death if a second concussion occurs before the first has resolved' was answered correctly by roughly two thirds of participants (76.7%). Under half of participants (49.3%) correctly stated that a GP/Doctor is recommended to perform a medical review prior to a return to contact-based rugby. Correctly identifying the recommended minimum relative rest period following concussion for both adults and youth players (14 days) was achieved by roughly half of participants (51.5%). Despite low overall scores, male participants (58.4% 0.6 ± 0.5) scored significantly higher than female counterparts (38.3% 0.4 ± 0.5) $t(138)=2.2$ $p=.032$.) for this question. No other significant knowledge theme score differences were observed between cohorts.

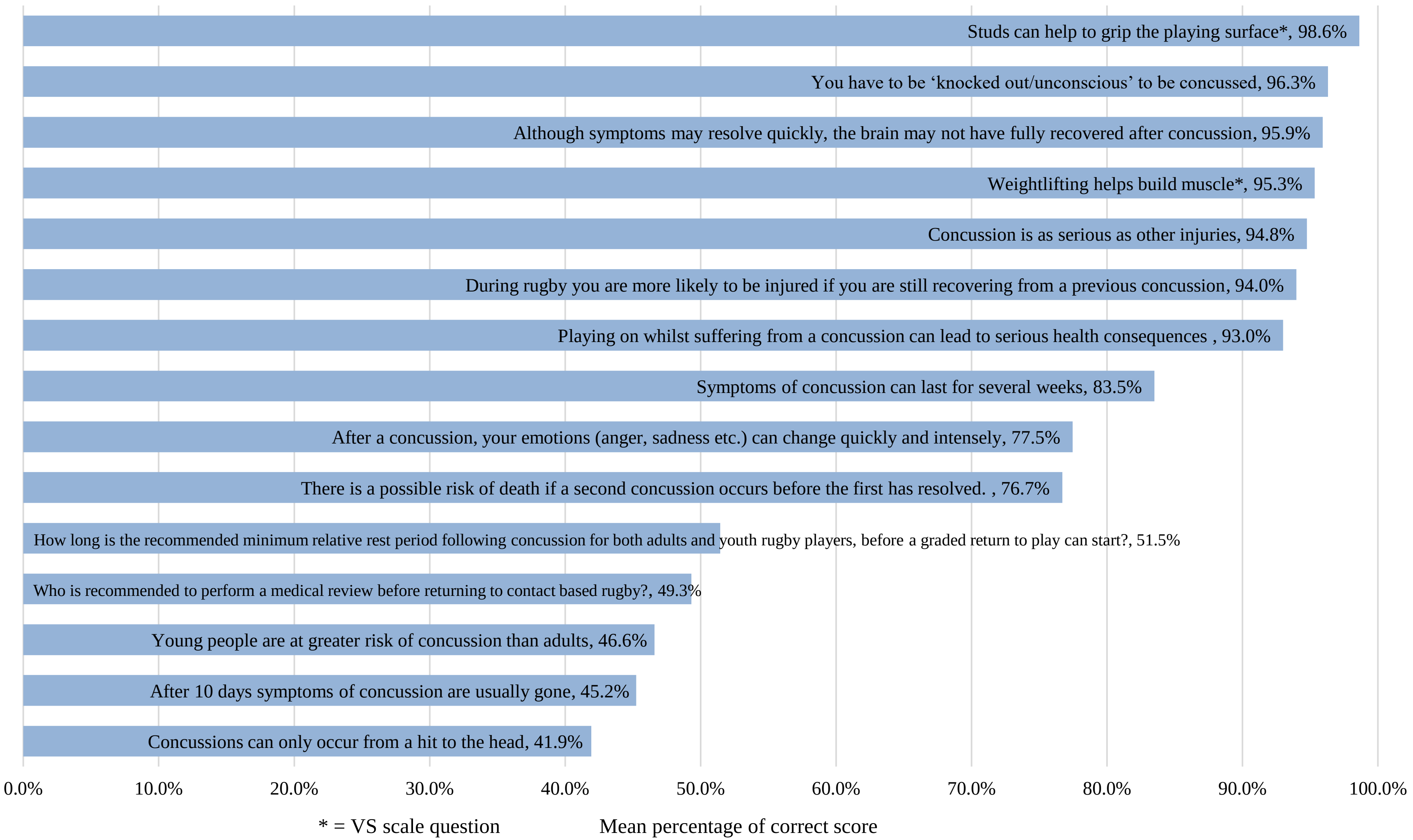


Figure 5.9 Ranked overall concussion knowledge question scores as a mean percentage of correct

### 5.3.5 Concussion Attitude Index

An overall mean CAI safety score of 76.0% (129.3/170 ± 14.8) was observed. No significant differences in CAI scores were observed between sex, age group, previous concussion or DBaH completion. (Figure 5.10) A small but significantly greater mean CAI difference was identified in private school attending participants (77.8%, 132.2 ± 14.0) over state school counterparts. (74.5%, 126.6 ± 15.1) (U=26141.5 p=.00001). Greater rugby playing experience (7-15 years) (77.4% 131.6 ± 15.0) also led to small but significant positive differences in CAI safety scores over players with less experience (0-6 years). (75.1% 127.6 ± 14.5) (U=27563.0 p=.00496).

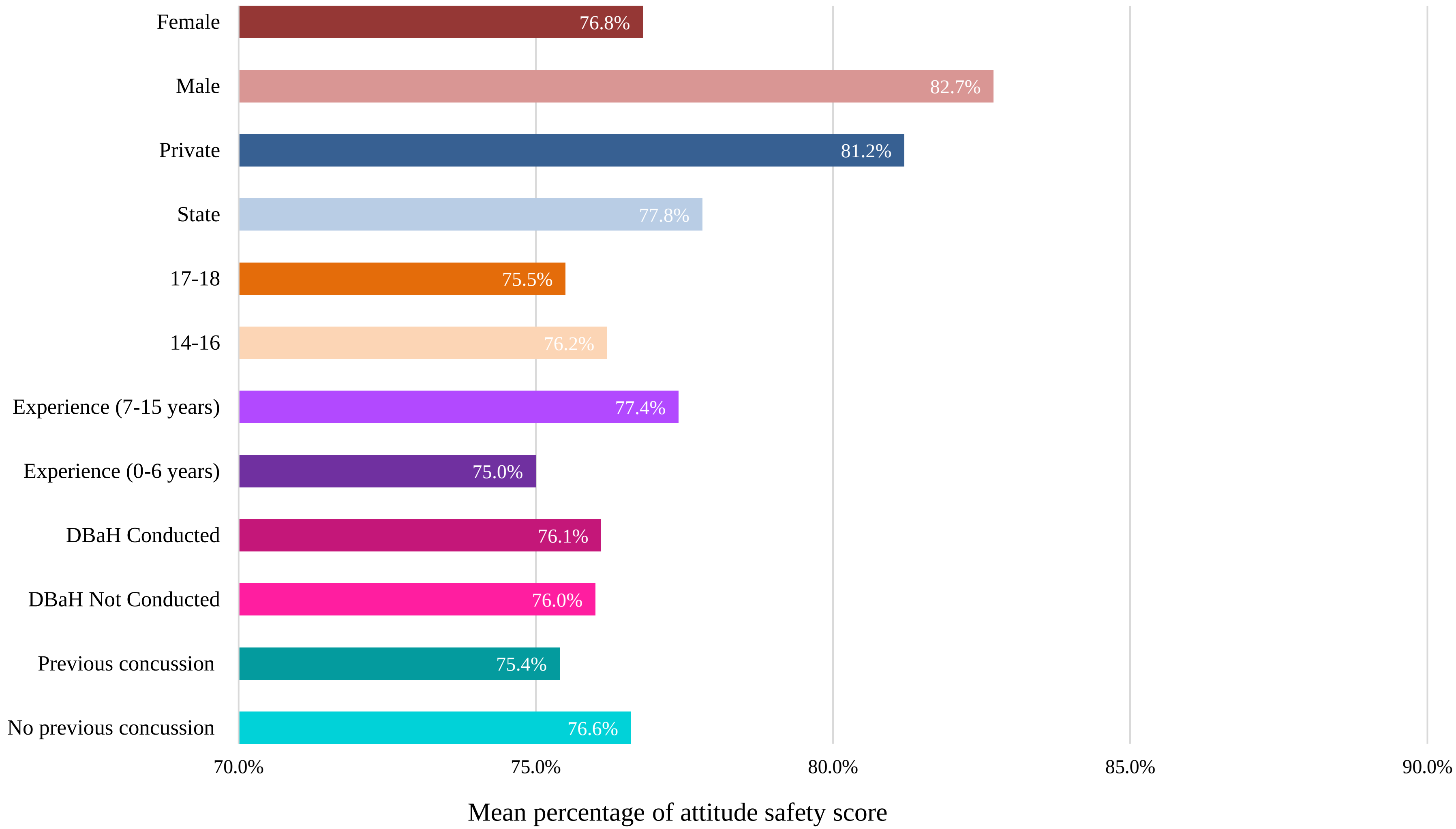


Figure 5.10 Mean percentage CAI scores by cohort

### 5.3.6 Concussion Attitude Themes

Statements were grouped into nine themes for cohort analysis and are ranked in order of attitude safety (Figure 5.11). Participant scores were determined through five-point Likert scale answers from Strongly Agree to Strongly Disagree. One hundred percent scores would indicate all participants scoring a maximum five points, the attitude deemed most safe, for each statement (Figure 5.12). Of the nine concussion attitude themes, 'Pressure to Return' produced the highest mean percentage attitude safety score of 80.8%, (4.0 ± 1.1). Within this theme participants rated their level of agreement with the statement 'I have been put under pressure by a (stakeholder) to return to play when I am still experiencing symptoms of concussion'. Disagreement to the statement was highest for 'Coach/Teacher' (84.5% 4.2 ± 1.0). followed by 'Parent/Guardian' (84.0% 4.2 ± 1.0), 'Teammate(s)', (80.0% 4.2 ± 1.1) and lastly, 'Myself' (74.5% 3.7 ± 1.2). The only significant cohort difference was observed in the lowest safety scoring statement, 'myself', where older participants demonstrated significantly less attitude safety towards self-administered pressure to play than younger participants ($t$(513)=3.36 p=.0008).

The 'Reporting Triggers' theme included eight circumstances following an impact that might prompt a player to stop playing and report symptoms. An overall attitude safety score of 79.9% (32.0 ± 5.4) was observed with the safest attitude towards symptom reporting triggered by 'Vomit or feel nauseous' (86.4% 4.3 ± 0.8) and the least safe attitude demonstrated when a participant might, 'Feel sensitive to light and noise'. (74.5% 3.7 ± 1.0) (Figure 5.13)

Two similar themes were used to identify participants attitudes towards the RTP decision making choices of coaches (Coach Lead RTP, 79.8% 8.0 ± 1.8) and Physio's (Physio Lead RTP, 77.8% 7.8 ± 1.7) (Figure 5.14). As with previous survey's,(329)(371)(423) this attitude theme included mirrored statements prefixed by either ‘Most players’, a reference to personal attitudes, or ‘My teammates’, a reference to perceived social norms. No significant differences were observed between participants responses to either context.

The concussion attitude theme ‘RTP Time’ uses the scenario; “The Fullback experiences a concussion during the first game of the season. The Flanker experiences a concussion of the same severity during the cup semi-final. Both players had persisting symptoms..."(Figure 5.15) The statements that follow encourage participants to reveal differences in RTP attitude between match circumstances that might illicit differing levels of participation value. As with “Coach lead RTP’ and ‘Physio Lead RTP’, The statements included the mirrored prefixes ‘Most players’ and ‘My teammate(s)’ No significant differences were observed between cohort responses to all four scenarios.

As with ‘RTP Time’ the ‘Reporting Norms’ theme (73.9% 14.8 ± 2.9) included two mirrored scenario responses. (Figure 5.16) Despite notably higher mean attitude safety scores surrounding the reporting of continued symptoms to a coach, (82.0% 4.0 ± 0.9 and 81.0% 4.0 ± 0.9) participants demonstrated far lower attitude safety towards choosing to play whilst experiencing a minor SRC related headache. (66.3% 3.3 ± 1.0 and 66.6% 3.3 ± 1.1) This finding was consistent across all cohorts.

The ‘Prevention Strategies’ theme (Figure 5.17) details participant understanding of the potential risk reduction qualities of tackle technique, head guards and gum shields and suitable warm-up’s. It also asks the participant to rank how important an understanding of concussion is as a rugby player. Participants demonstrated safer attitudes towards the appreciation that an understanding of concussion (91.7% 4.6 ± 0.7) and tackle technique (89.0% 4.5 ± 0.8) are important in concussion prevention, than an appreciation that suitable warm up's (64.6% 3.2 ± 1.1) can reduce risks but head guards, gumshields may not as stated by the RFU(7)(44.8% 2.2 ± 1.1). The 'Prevention Strategies' theme was the only multi-statement theme to record a Cronbach α score below the 0.7 level considered acceptable.(462) This result is unsurprising considering the stand-alone nature of the statements which naturally reduces the themes internal consistency.

The 'Reporting Consequences' theme (68.5% 4.6 ± 1.8) describes the potential drivers behind non-disclosure with the lowest mean attitude safety score from "If I report what I suspect might be a concussion, I will not be allowed to start training and playing when I think I am ready" (50.3% 2.5 ± 1.1) (Figure 5.18). Female participants demonstrated significantly safer attitudes towards this key measure than male counter parts. ($t$ (513)=3.1, p=0.002.) No other differences were observed between cohorts.

The concussion attitude theme that revealed the least safe attitudes was 'Symptomatic RTP' (55.8% 2.8 ± 1.1) (Figure 5.19) The theme contained a single statement 'If all the symptoms of concussion have gone, you can safely return to contact rugby'. When concussion attitude safety scores were divided by cohort, male attitudes towards this statement were significantly safer than females, ($t$(513)=2.9, p=.004) as were private school attending participants over state school counterparts. ($t$(513)=2.9, p=.004) No other significant differences were observed between cohorts.

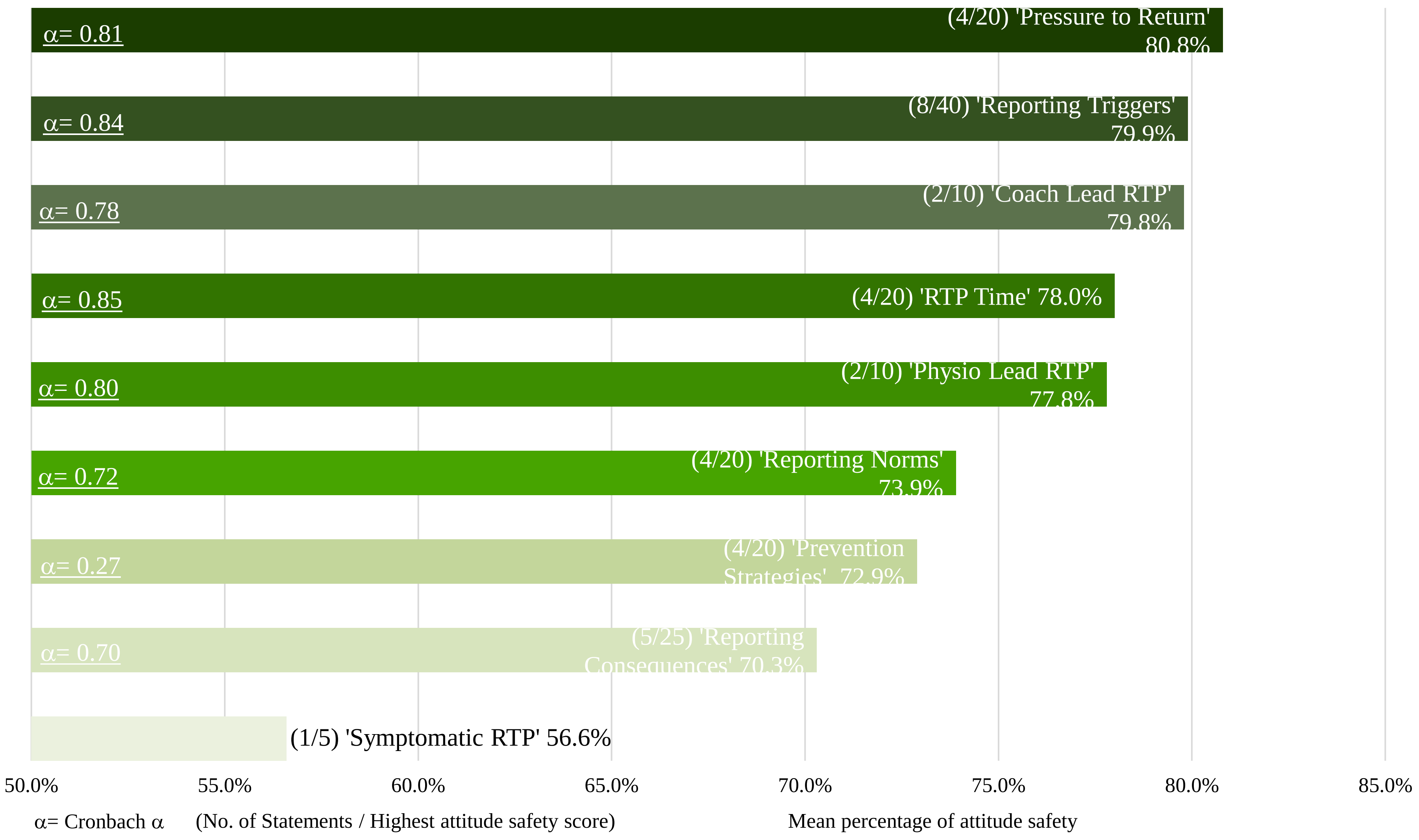


Figure 5.11 Overall mean concussion attitude theme scores as a percentage of safest attitude

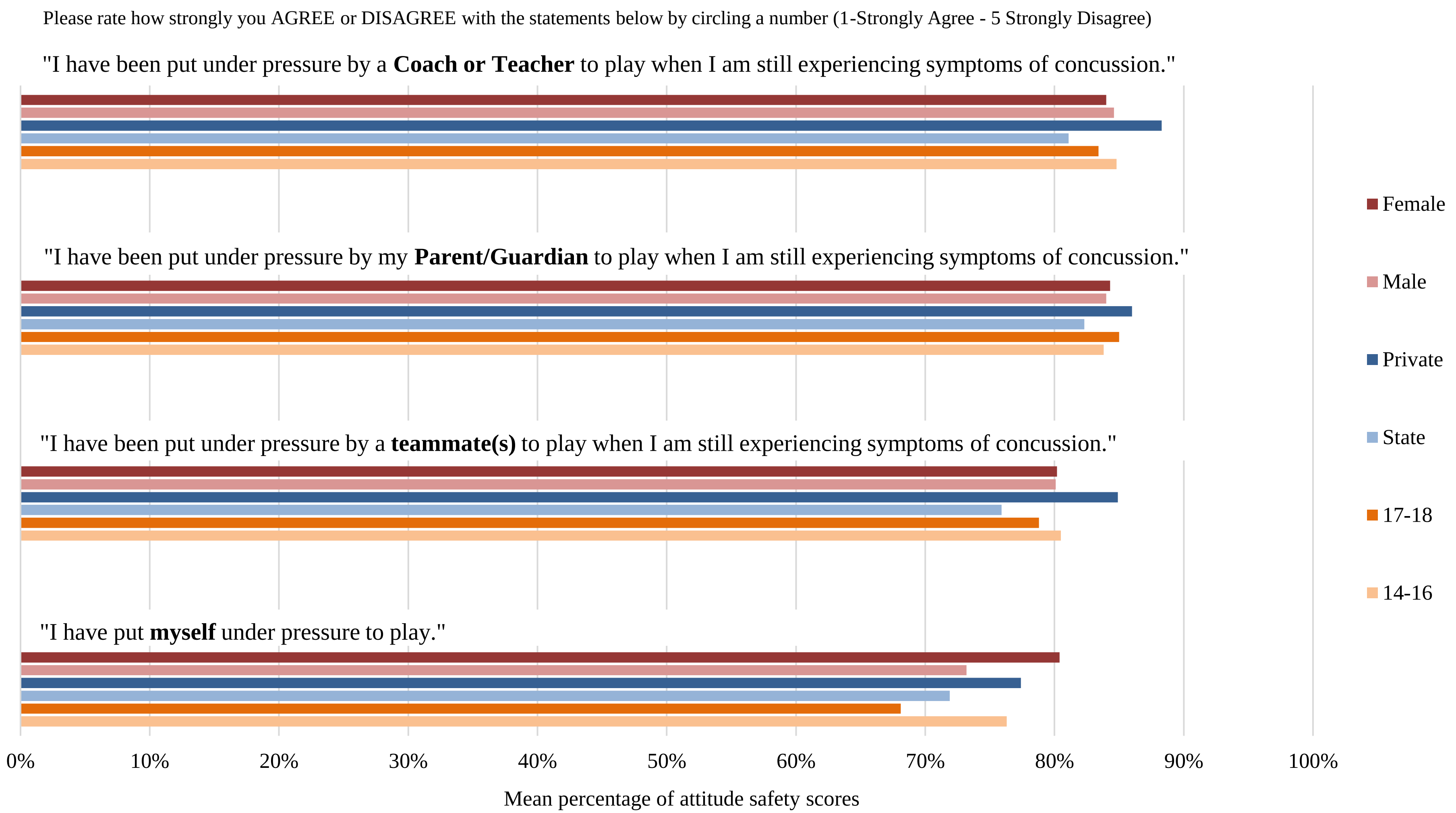


Figure 5.12 Ranked mean percentage of attitude safety scores for the 'Pressure to Return' theme by primary cohort

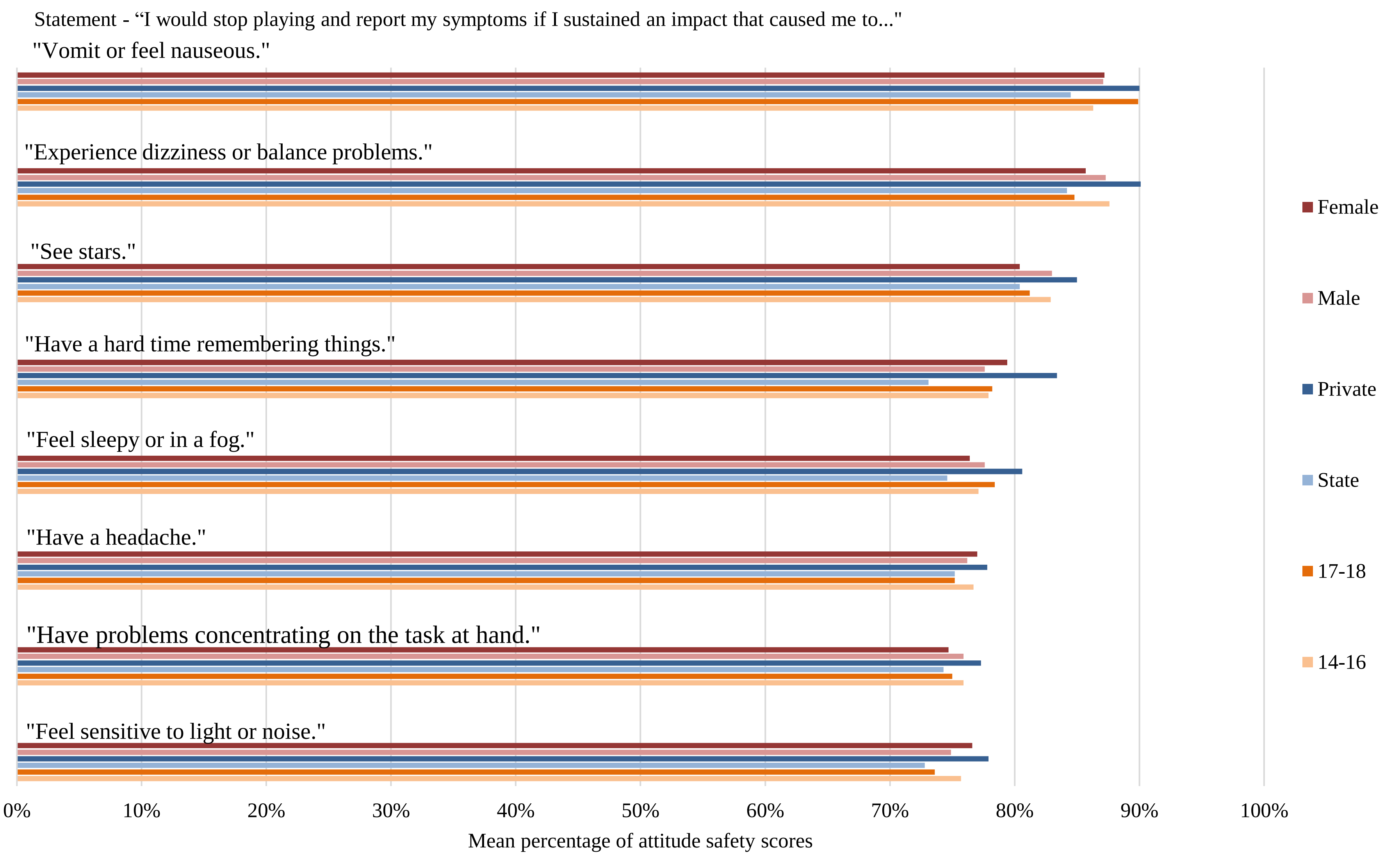


Figure 5.13 Ranked mean percentage of attitude safety scores for the 'Reporting Triggers' theme by primary cohort

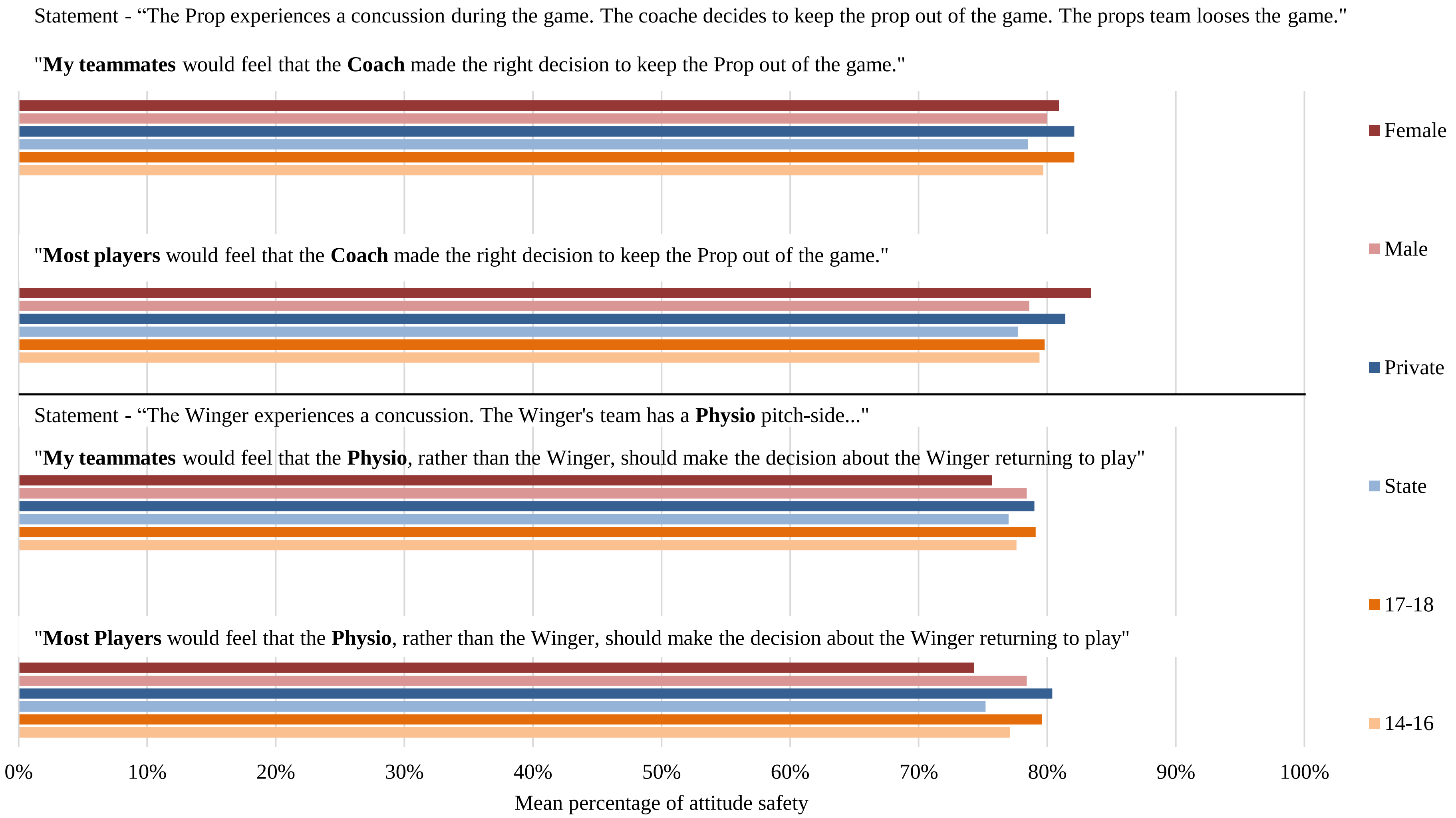


Figure 5.14 Ranked mean percentage of attitude safety scores for the 'Coach Lead RTP' and 'Physio Lead RTP' themes by primary cohort

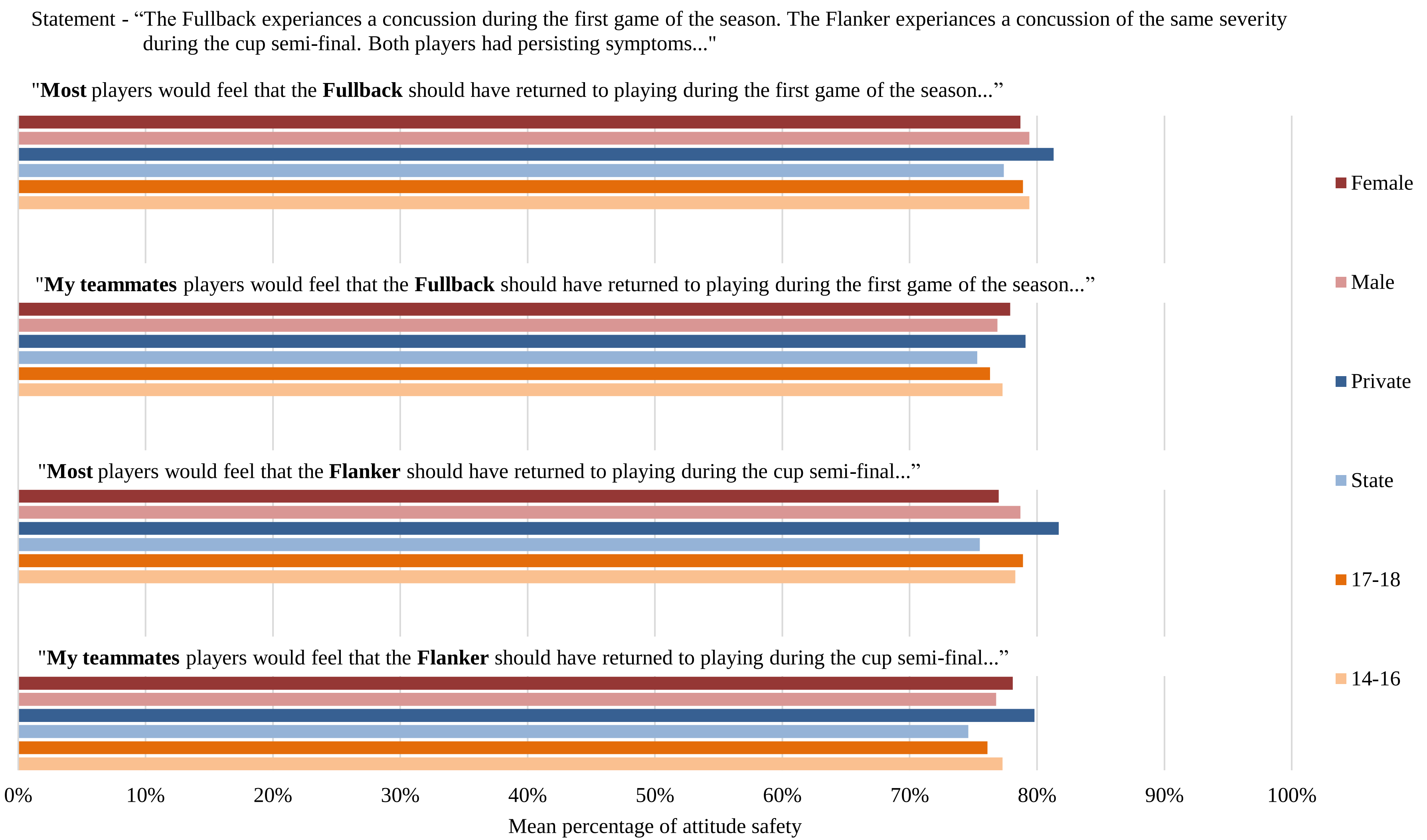


Figure 5.15 Ranked mean percentage of attitude safety scores for the 'RTP Time' theme by cohort

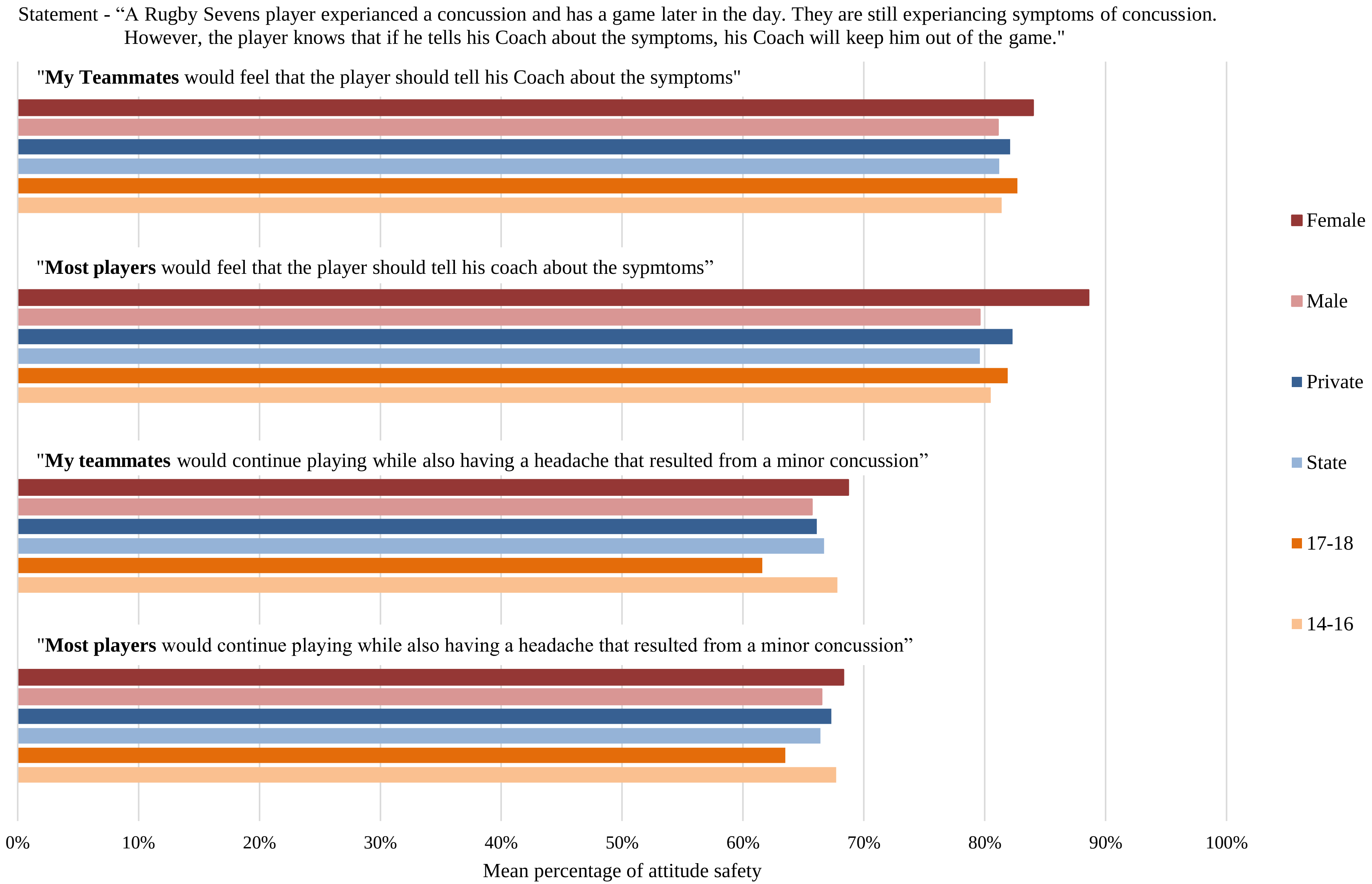


Figure 5.16 Ranked mean percentage of attitude safety scores for the 'Reporting Norms' theme by primary cohort

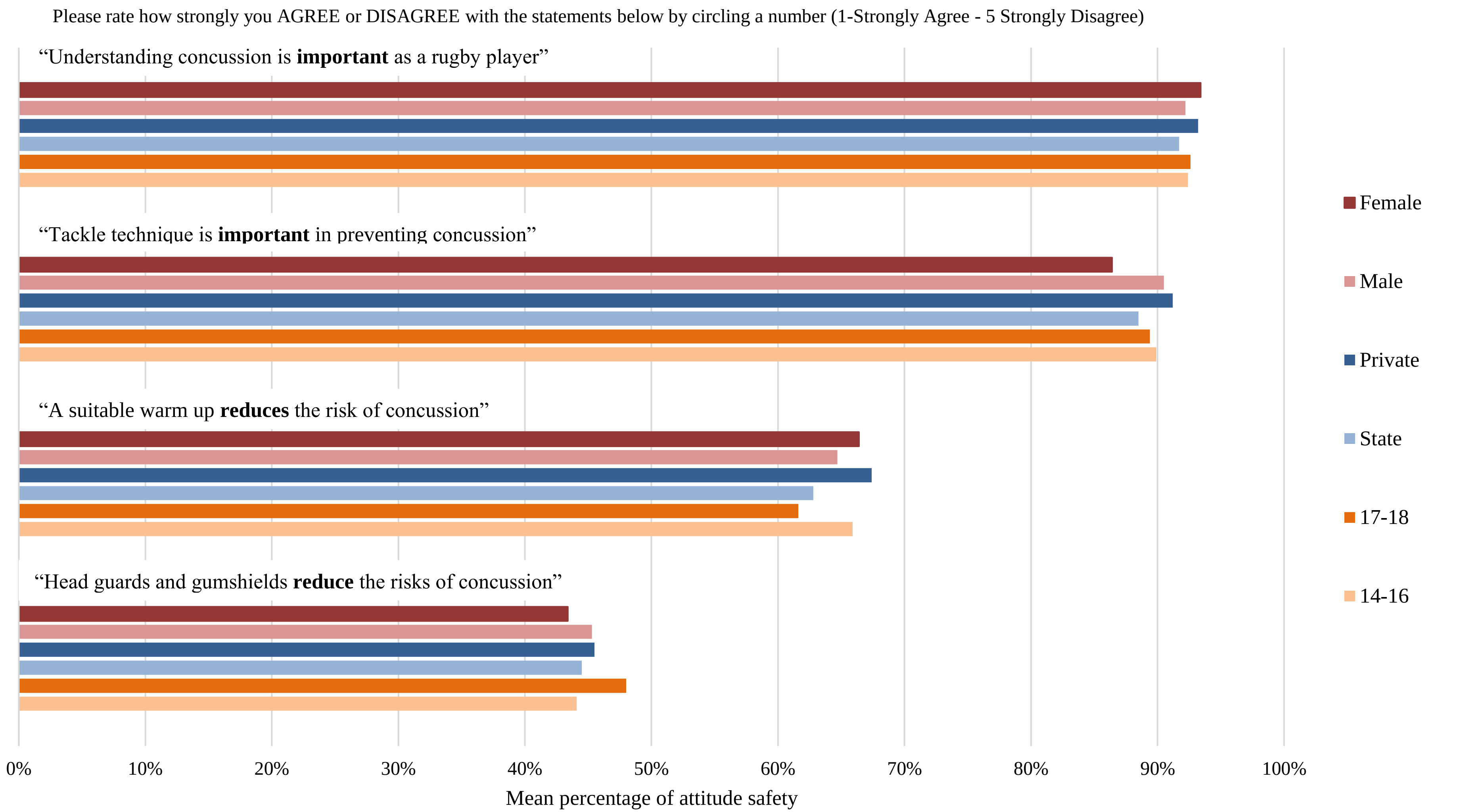


Figure 5.17 Ranked mean percentage of attitude safety scores for the 'Prevention Strategies' theme by primary cohort

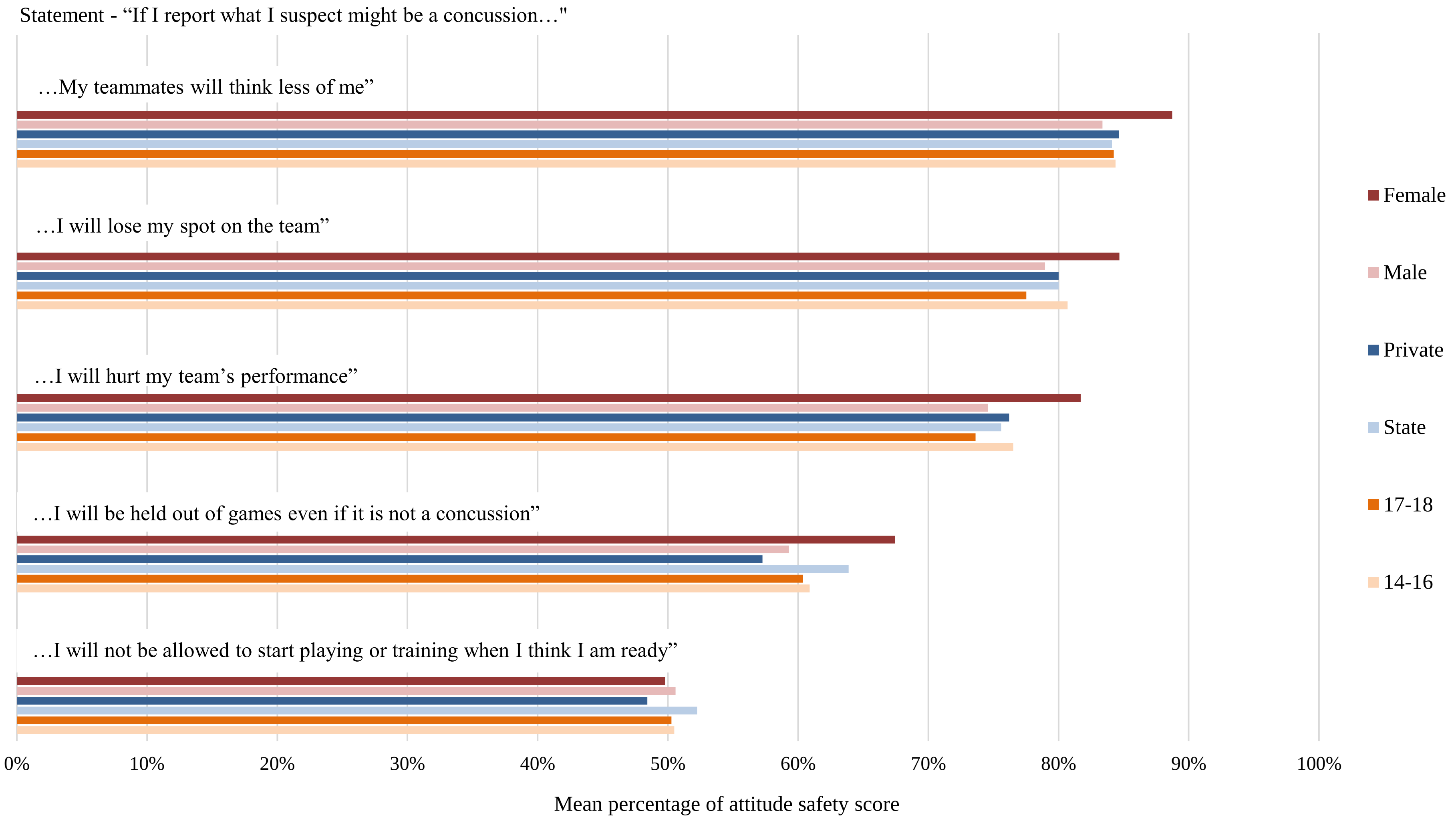


Figure 5.18 Ranked mean percentage of attitude safety scores for the 'Reporting Consequences' theme by cohort

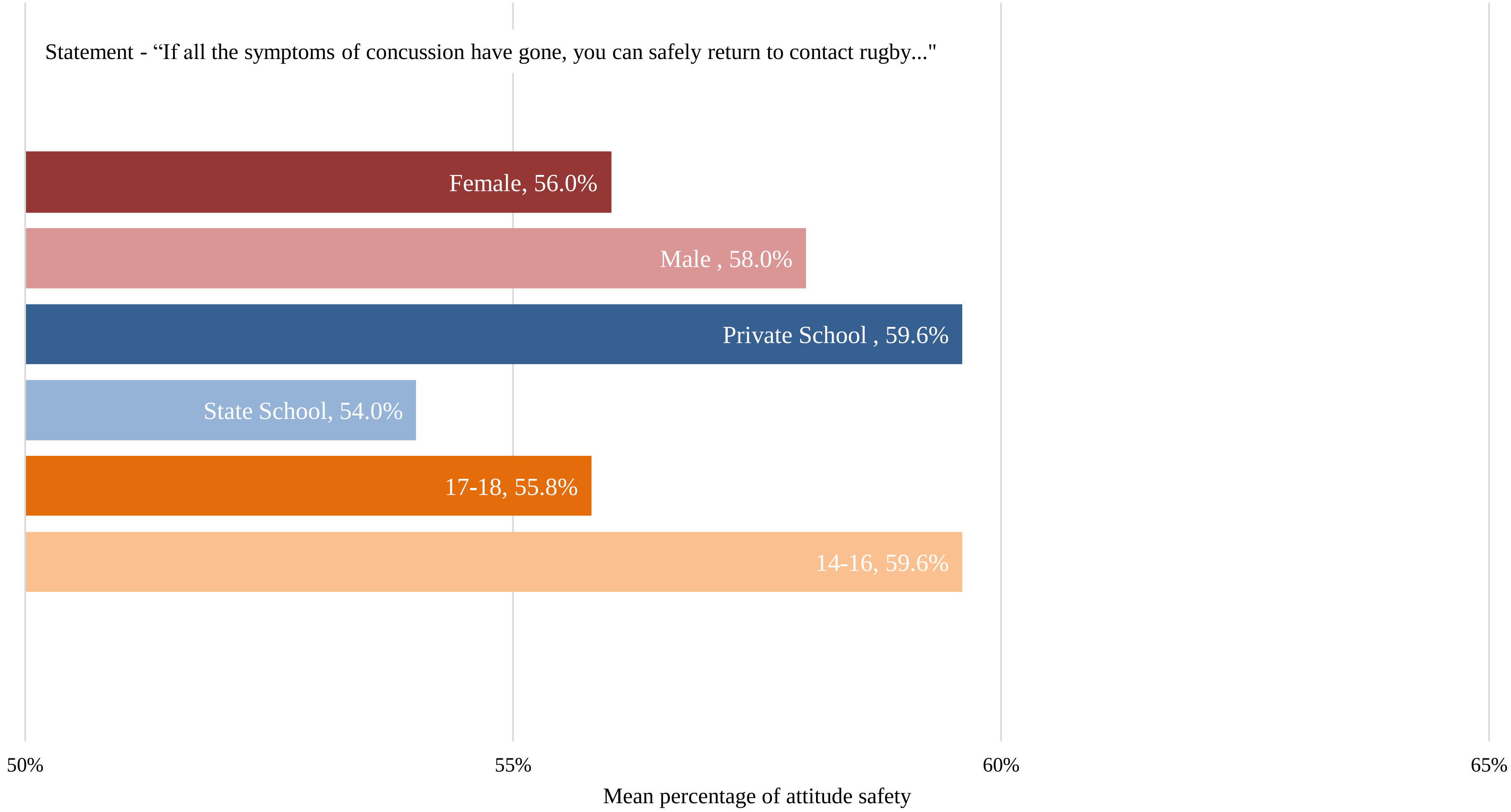


Figure 5.19 Ranked mean percentage of attitude safety scores for the 'Symptomatic RTP' theme by primary cohort

### 5.3.7 Concussion Attitude Statements

Overall mean participant scores as a percentage of attitude safety were ranked for each concussion attitude statement (Figures 5.20a and 5.20b). Participants cited four statements they most agreed with that achieved mean attitude safety scores over 85%. These were ‘Understanding concussion is important as a rugby player’ (91.7% 4.6 ± 0.7), ‘Tackling technique is important in preventing concussion’ (89.0% 4.6 ± 0.8) ‘I would stop playing and report my symptoms if I a) sustained an impact that caused me to ‘vomit or feel nauseous’, (86.4% 4.3 ± 0.8) and b) ‘experience dizziness or balance problems’ (86.3% 4.3 ± 0.8). Five statements resulted in attitude safety scores below 65%. These were ‘Head guards and gum shields reduce the risk of concussion’ (44.8% 2.2 ± 1.1), ‘If I report what I suspect might be a concussion, I will not be allowed to start playing or training when I think I’m ready’ (50.3% 2.5 ± 1.0), ‘If all of the symptoms of concussion have gone, you can safely return to contact rugby’ (56.5% 2.8 ± 1.1), ‘If I report what I suspect might be a concussion, I will be held out of games even if it’s not a concussion’ (60.5% 3.0 ± 1.1), and ‘A suitable warm up reduces the risk of concussion’ (64.6% 3.2 ± 1.1).

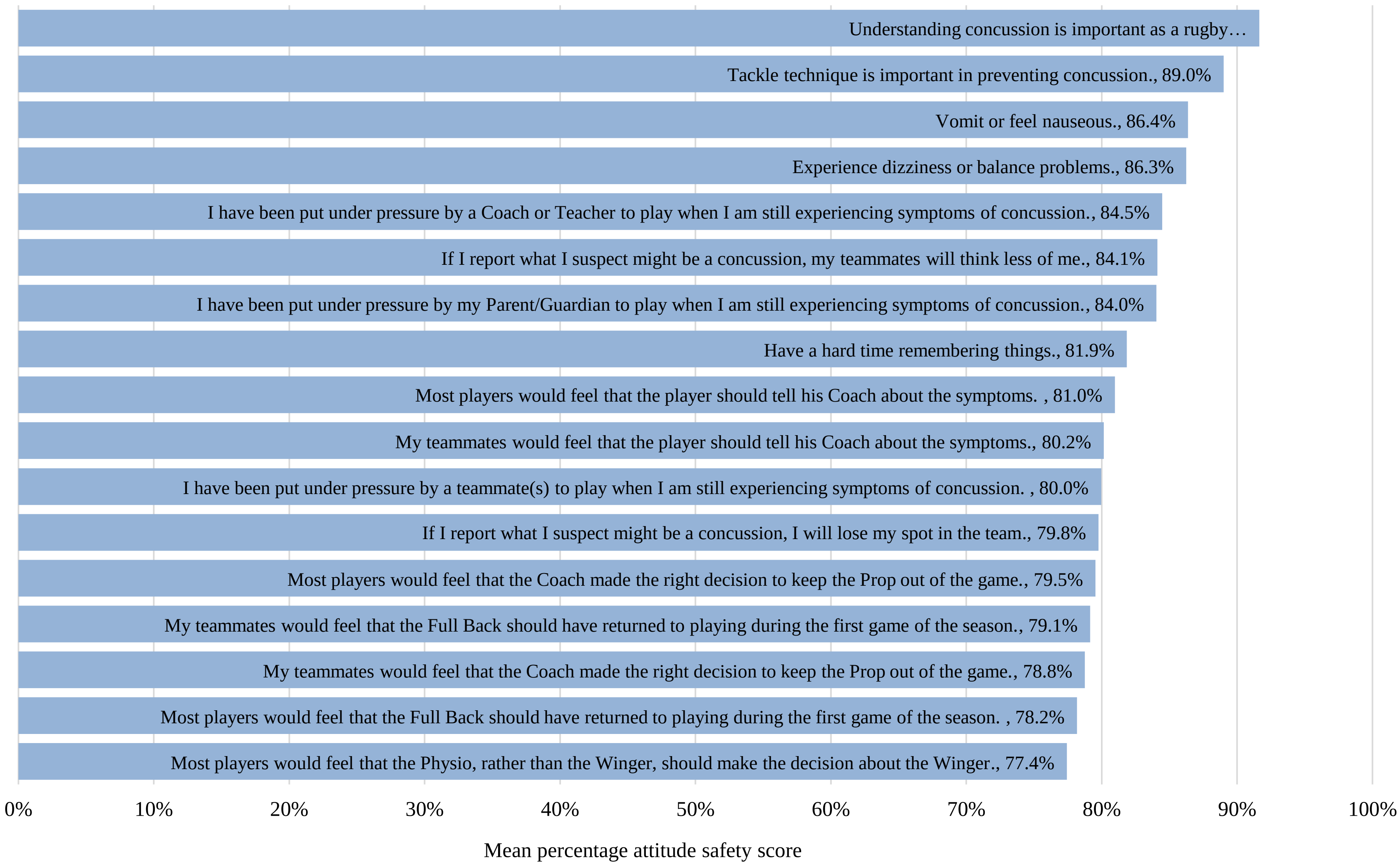


Figure 5.20a Ranked concussion attitude statements as a mean percentage of attitude safety (upper)

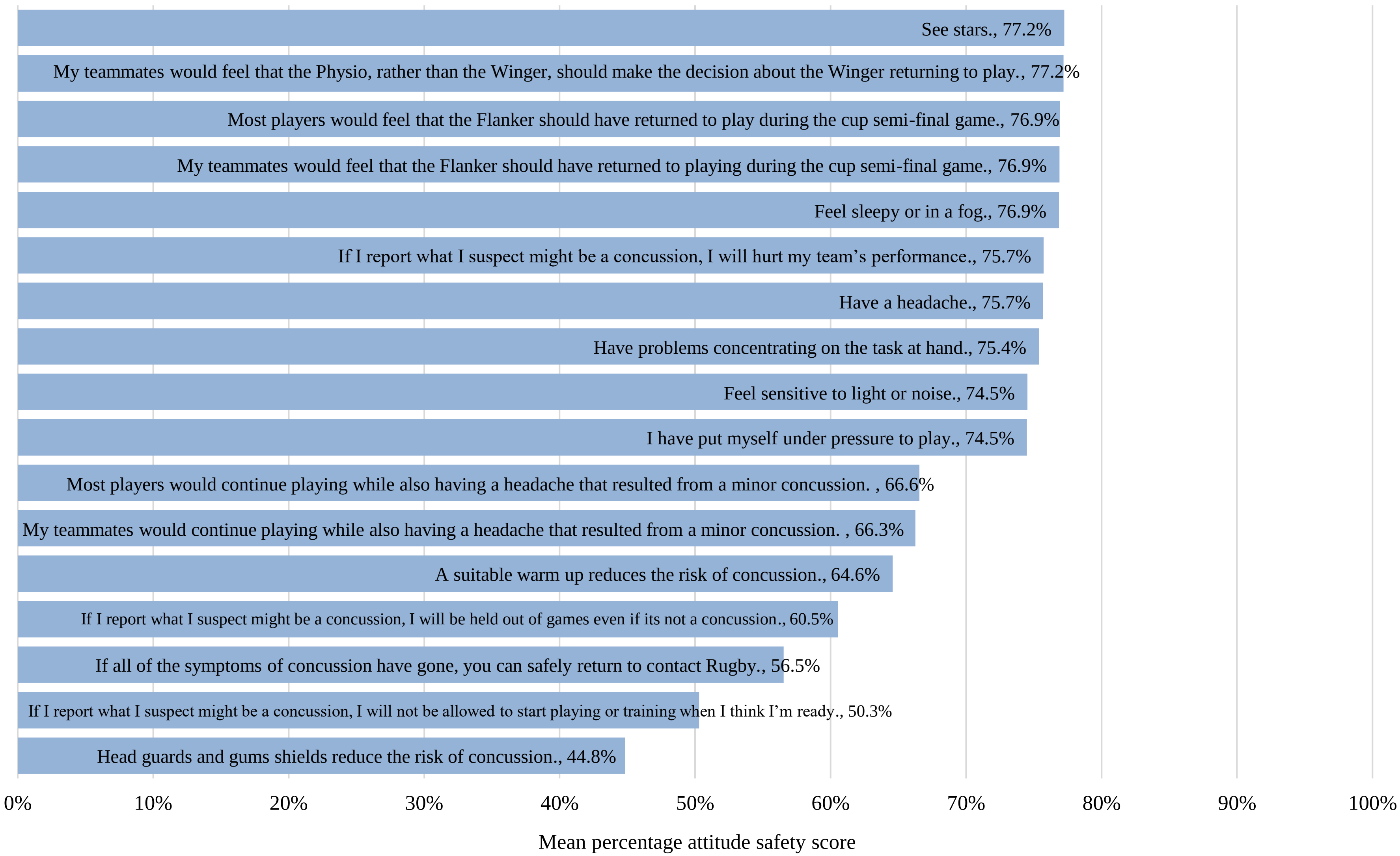


Figure 5.20b Ranked concussion attitude statements as a mean percentage of attitude safety (Lower)

### 5.3.8 Concussion Knowledge and Attitude Associations

No association between overall CKI and CAI was found ($r$(513) =.139, p = .889). (Figure 5.21) When reviewing the potential influence of individual knowledge theme components on total CAI, the ordinal logistic regression model identified that the True or False concussion knowledge section presented the only significant positive predictive effect on attitude safety ($\chi^2(2) = 17.359$, $p = .027$.) When further sub divided, the only individual knowledge response to represent a positive predictive effect on CAI safety was answering correctly 'Symptoms of concussion can last for several weeks. ($\chi^2(2) = 10.089$, $p = .001$.) Despite no association between total CKI and CAI scores, CKI was significantly associated with two of the nine individual attitude themes. A small significant positive relationship was observed between safer attitudes towards 'Reporting Norms' ($r$(513) =.127, p = .004). and higher CKI (table 3.) When this theme was divided into two sub-groups, a significant small positive relationship remained between safer attitudes towards 'My teammates/Most players would continue playing while also having a headache that resulted from concussion' ($r$(513)=.128, $p$=.004), and CKI, but not with attitudes towards 'My teammates/Most players would feel that the player should tell his Coach about the symptoms', ($r$(513)=.0728, $p$=.099) and CKI. In addition, higher CKI knowledge was also found to have a very small significant negative relationship with attitude towards concussion prevention strategies. ($r$(513)=.148, $p$=.001). No other concussion knowledge responses were significantly associated with collective or individual attitude themes. No differences in concussion knowledge or attitude were observed in participants who had not experienced concussion in the past over those who stated that they had experienced concussion in the past.

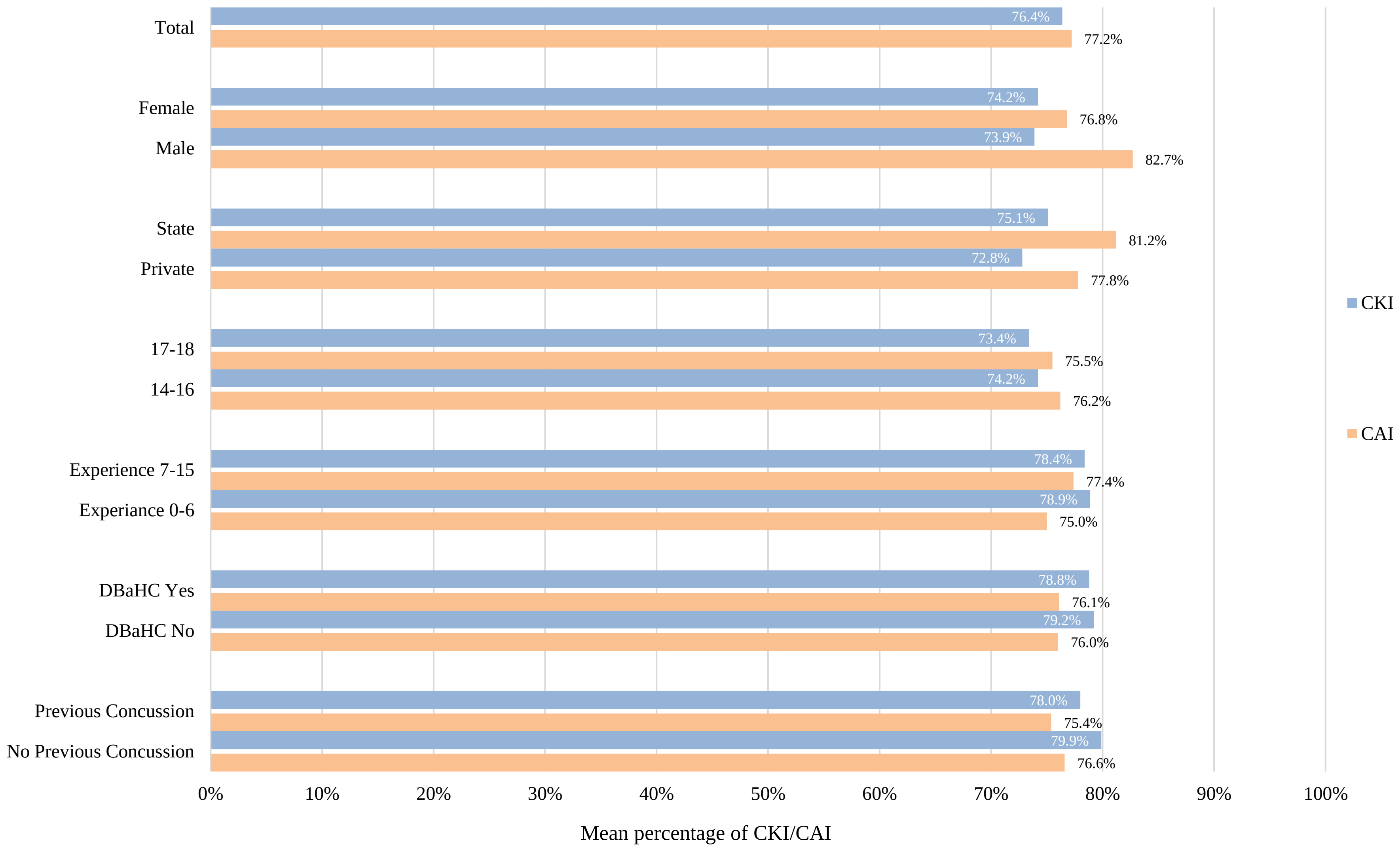


Figure 5.21 Concussion knowledge and attitude index scores as a percentage of correct and attitude safety

### 5.4 Discussion

Almost half (48.2%) of participants reported experiencing one or more youth rugby related concussion. This reinforces the need to explore concussion knowledge and attitudes and supports rugby governing bodies concussion risk reduction focus. The figure sits in the upper end of a broad range of reported concussion within youth rugby.(19.4%-69%)(43)(44)(348)(350)(363)(366) The stated rugby concussion incidence figure of 48.2% does not, however, reflect the true prevalence of youth rugby related concussion which has yet to achieve consensus. In addition, no difference in concussion knowledge or attitude was observed between participants who had, and had not experienced previous concussion. This is counter to previous research suggesting that prior concussion experience leads to less safe attitude towards concussion and negative concussion disclosure.(368) It has been hypothesised that this may be a result of perceiving no negative consequences after continued symptomatic play, and in turn no benefits to injury reporting.(463) It may be that participants in the RUCKAS-YOUTH survey are more aware of, and influenced by, current expected behaviour norms than participants of these now dated investigations.(368)(463)

This study reinforces the previously highlighted key role coaches and teachers play in communicating information and shaping attitudes towards SRC.(366) School and rugby club Coaches and Teachers represented the most frequent source of head injury information. Participants also commonly disagreed that a Coach or Teacher has applied pressure to play whilst still symptomatic. Despite this, 25.5% of participants either felt neutral towards, or pressurised, by a Coach or Teacher to play. Any degree of perceived coercion from any rugby stakeholder should not be overlooked considering the infrequent but considerable dangers a second impact may present.(16) Such events involving impacts to unresolved defuse cerebral swelling have been linked to deaths in sport despite the challenge of fully defining the relationship between the two injury events.(8) As such, Coaches and Teachers should continue to be considered key concussion knowledge and attitude behaviour change conduits within rugby but with their impact on head injury management regularly appraised.(1)

This study is the first to report the surprisingly low extent of stated DBaH online concussion education completion by participants. During correspondence with school Directors of Sport as part of the recruitment process, the majority report either onsite conduction of the programme or directing students to it, as part of school sport concussion policy. This would imply that poor participant awareness and/or memory of DBaH completion may account for an unknown amount of stated non-conduction. This feature was also found by Barden *et al*.(464) when reviewing the implementation of the RFU backed 'Activate' injury prevention programme. Players engaged in injury prevention pre-activity drills were frequently found to be unaware of their participation, despite significantly greater acknowledgment from coaches.(464) Although only a small proportion of participants cited DBaH completion, no significant differences in concussion knowledge or attitude were observed between those that did and did not cite prior engagement with the programme.

### 5.4.1 Concussion Knowledge

Due to the composite design of the RUCKAS survey, comparisons between prior SRC knowledge levels are possible. Participant concussion knowledge in this study was frequently higher than common elements previously observed in other youth SRC investigations.(43)(350)(362)(366) When six directly comparable concussion knowledge questions from the Kearney and See(350) investigation of a youth rugby population (mean 59.0% correct), were compared to RUCKAS-YOUTH study participants scores (mean 83.8% correct), an average increase of 11.6% per question in knowledge accuracy was found.(350) Despite only a five-year difference between the studies, the continued rise in concussion awareness and education would appear causal. Concussion knowledge levels from the RUCKAS-YOUTH survey appear more aligned to recent studies of youths and adult cohorts,(423)(465)(466) suggesting an upward trend in general concussion knowledge over time. DBaH completion cannot. however, be considered directly responsible as its stated conduction was low and no association with raised concussion knowledge scores was observed.

The highest scoring knowledge questions involved the recognition of the signs and symptoms of concussion, suggesting that youth rugby players are broadly aware of concussion in a rugby context. This contradicts the now dated conclusion that failings in concussion symptom awareness are largely responsible for non-disclosure.(343) Despite this, gaps in participant concussion knowledge were apparent. The lowest knowledge scores reveal mixed appreciation of concussion complications and appropriate return to play. Most concerningly, the majority of participants were unaware that they are at greater risk of prolonged and fatal consequences of concussion,(14) despite being less likely to experience a concussion than an adult player.(9)(13)(459) In addition, roughly a quarter of participants were not aware that there is a possible risk of death if a second impact occurs before the first has resolved. If youth rugby players incorrectly perceive that they are no more susceptible to the effects of concussion than adults, they may under appreciate risks when making symptom disclosure decisions. Ensuring that youth rugby players and stakeholders are fully aware of heightened youth concussion risk, regardless of playing level, is essential.

As with previous investigations,(1)(44) participants were commonly unaware of the recommended minimum rest period following concussion, and that a GP/Doctor is recommended to perform a medical review prior to contact-based rugby. This may seem an obvious target for educational intervention, however, the impact of concussion guideline awareness may be more complex. As discussed below, a key finding of this research supports the rationale that a desire for continued rugby participation is a key driver of symptom non-reporting.(366) Whether increased player awareness of stand-down periods within a complex GRTP promotes greater safety through adherence, or heightens the likelihood of non-reporting, remains debatable.(366) Until the diagnostic capabilities required for individualised GRTP reach grassroots levels, negating this effect may remain challenging for governing bodies.

### 5.4.2 Concussion Attitude

The observed mean total CAI safety score of (76.0% 129.3 ±14.8) matches CAI scores in recently reported adult community rugby club stakeholders.(423) This figure suggests broadly safe attitudes towards concussion, however discrepancies are apparent. When all concussion attitude statements are ranked for mean safety, patterns emerge. Preventative strategy understanding is polarised with mean attitude safety scores of 89.0% shown towards the understanding of the importance of tackle technique in concussion prevention, ranked the 2nd safest attitude score. In contrast, a mean attitude safety score of 44.8% was shown towards correctly stating that evidence suggests(467)(365) gumshields and headguards do not prevent concussion, ranked 33rd. Although not directly comparable, this figure aligns with Baker *et al.*(43) who report similarly low attitude safety towards gumshields and head guards within a cohort of u20 Irish rugby players.(see section 2.7.2.1). If youth rugby participants feel that equipment can help reduce the risks of concussion, it may influence their decision making and promote risk taking behaviours.(365)(468) As such, continued education surrounding the role and capabilities of such protective equipment for youth rugby players is imperative.

Just four places above with 64.6% mean attitude safety, was the belief that a suitable warm up reduces concussion risk. Prior to the publication of an RFU backed pre-activity injury prevention study in 2017,(469) the concept that pre-activity physical preparation could reduce rugby concussion risk was largely anecdotal. (see section 2.8.8) Since this time, rugby governing bodies have promoted pre-activity preparation as a concussion reduction strategy.(406) As no prior degree of participant awareness of it has been published, gauging any change in youth participant appreciation of pre-activity preparation over time is not possible. If pre-activity interventions are to form a key pillar of concussion risk reduction,(404) rugby participant awareness of its importance should be a primary focus of education interventions. The RUCKAS-YOUTH figures provide an initial understanding of attitudes towards pre-activity risk reduction from which future comparisons can be drawn.

As highlighted above and in section 2.5.8, understanding what both increases and decreases concussion risk remains integral to concussion prevention in rugby. Pleasingly, this is a sentiment shared by participants who demonstrate a mean attitude safety score of 91.0% towards the importance of understanding concussion. Despite this being the attitude participants rated the safest response to, the broader findings of the RUCKAS-YOUTH survey found concussion knowledge is not directly associated with concussion attitude safety. The high degree of importance placed on knowledge of concussion cannot, therefore, be used to imply safer attitudes towards symptom disclosure will ensue. It does, however, suggest that engagement in concussion education is welcomed by participants, an essential part of risk reduction interventions.

As with attitudes towards preventative strategies, attitudes towards triggers to symptom disclosure are polarised. The third and fourth highest rank statements were "I would stop playing and report my symptoms if I sustained an impact that caused me to - vomit or feel nauseous / experience dizziness and balance problems." In contrast, the same prefix followed by 'feel sensitivity to light or noise / have problems concentrating on the task at hand / have a headache, ranked 23$^{rd}$-25$^{th}$. This suggests that symptoms are considered hierarchical and in turn, proportional to disclosure intention. The more severe/observable, the more likely to promote reporting. No weighting has been placed on the signs and symptoms of concussion by governing bodies diagnostically, as any/all should trigger removal from play following a head injury at community levels.(see section 2.6.3.4) In addition, as second impact syndrome has been proposed to carry considerably higher risks than an isolated injury, regardless of severity,(470) disassociating symptom severity with reporting intention should be a key goal of risk reduction interventions.

Three of the four attitude statements within the 'Pressure to Play' theme occupy the upper quartile of the attitude safety ranking scale when all individual concussion attitude safety scores are ranked. (see figure 5.20a) No significant differences were observed between participants attitudes towards external pressure from Coach's, Teammates and Parents. The significant outlier ranked 26$^{th}$ overall (Figure 5.20b) was, 'I have put myself under pressure to play'. Although the overall mean attitude safety score of this statement still suggests the majority of participants feel they have not put themselves under pressure to play, it would infer the drive for continued participation is more commonly intrinsic than extrinsic. The 'Reporting Consequences' theme details some of the intrinsic drivers behind symptom non-reporting. The lowest scoring safety attitudes were "If I report what I suspect might be a concussion, I will not be allowed to start training and playing when I think I am ready", (50.3% 2.5 ±1.1) and 'If I report what I suspect might be a concussion, I will be held out of games even if it's not a concussion" (50.3% 2.5 ±1.1). This suggests that, not only is being excluded from play the most powerful of non-disclosure drivers, but participants personal readiness judgements and desire for self-reliance play a key role.(325)(see section 2.7.3) As a result, if players feel that perceived low initial symptom severity is associated with lower secondary risk, they may be more inclined to withhold symptom reporting if it might lead to exclusion.(42) As the 'Reporting Consequences' theme led to the second lowest overall attitude theme safety score, (Figure 11) each of the attitudes towards the five statements should be addressed within concussion behaviour change interventions.

As with the ‘Reporting Triggers’ and ‘Prevention Strategies’ themes, ‘Reporting Norm’s led to a split in attitude safety scores despite each statement presenting the same supposition. When participants were asked whether ‘Most players’, and ‘My teammates’ should report still experiencing symptoms to a coach prior to a game, 81.0% and 80.2% attitude safety scores were observed.(Figure 16.) Participants were then asked if ‘Most players’ (66.3%) / ‘My teammates’, (66.6%) would continue playing whilst also having a headache that resulted from a minor concussion. Whilst presenting a similar scenario, the questions split the constructs of self, ‘most’, and contextual norms, ‘My teammates’ within the first statements to infer participant perception of what ‘should’ happen when symptomatic. Within statements three and four, participants anticipated behaviour when placed in the same scenario is revealed. The results suggest that an acceptable understanding of appropriate behaviour (statements one and two) is not fully matched by corresponding reporting intention (Statements three and four). This, again, reveals a disassociation between knowledge of expected social norms and resulting attitudes towards disclosure.(39)

The pattern of no significant difference in reported attitudes between ‘Most’ and ‘My teammates’ statements was found in this and all other themes suggesting self-predictive behaviour is commensurate with perceived social norms.(39) This would be more encouraging if perceived social norms were of the highest possible attitude safety. It does suggest that behaviour change interventions that focus on collective team attitudes and responses are appropriate within a youth rugby context.(471)

### 5.4.3 Sex Differences

Despite previous inclusion within the Kearney and See(350) youth rugby concussion attitude assessment,(N=17) this study is the first to include a sizable female youth rugby playing population (N=94) Despite no significant total concussion knowledge and attitude differences between the sexes, some differences in individual knowledge and attitude components were observed. Females demonstrated significantly less-safe attitudes than males when stating ‘If all the symptoms of concussion have gone, you can safely return to contact rugby’. Despite inclusion within the attitude section of the survey, the answers to this statement could be influenced by limited knowledge of GRTP protocols, rather than a consciously unsafe attitude. This potential lack of appreciation could be linked to the only other metric to differ between the sexes, the greater level of rugby experience of male participants.  Rugby experience was a factor observed to be positively associated with safer concussion attitude scores. If less experience is associated with this specific lack of GRTP understanding/attitude, it should be a focus of concussion education.

The key difference between the sexes was the significantly lower attitude safety scores recorded by male participants with regard to the consequences of reporting. The lowest scoring statements in this theme involved being held out of games. As a theme, and for four out of five questions within the theme, male participants demonstrated significantly more agreement with unsafe attitudes surrounding the consequences of symptom reporting than females. This cannot be explained by SRC knowledge, as an equal appreciation was found and no association between knowledge and reporting consequence scores was apparent. Although no specific literature as to why males demonstrate less-safe attitudes towards SRC RTP has been published, theory of the sporting attitude differences between the sexes has been widely presented. A prominent foundation is that males commonly place greater value on participation than females, which in an SRC context, supports the hypothesis that greater participation value reduces the likelihood of symptom disclosure.(368) If, and why, young males may value rugby participation more than young females is debatable. Evidence ranges from evolutionary perspectives that report males being more likely to seek competition and direct physical confrontation,(472) to research suggesting that males are more likely to report risk taking behaviour within sporting contexts.(473)(474). Further research that unpacks the links between perceived sporting importance and reporting intention is needed in order to positively influence youth risk/reward decision making.

### 5.4.4 School Attendance

This study is the first to compare SRC related knowledge and attitudes between state and private school attending participants. As discussed above, regardless of any potential gap in reported and actual DBaH completion, private school participants reported higher completion rates than state school counterparts. Whilst no significant differences in total concussion knowledge were observed, private school attending participants reported significantly safer attitudes towards concussion.  As no association between DBaH and concussion knowledge was observed, it would appear an unlikely single contributor to heightened private school participant SRC attitudes. No prior publication has investigated the sporting attitude differences between state and private school attending pupils. The differences between the sectors may prove revealing. The primary divergence lies in the amount of sports participation afforded. Private schools have been cited as conducting almost three times as much sporting activity than state counterparts.(475) Despite a reduction in participation,(476) rugby is still the primary winter sport of many UK private schools. This means that not only are private school pupils likely to have more weekly rugby engagement, they will also be exposed to a higher degree of rugby coaching, and more competitive match play. As the degree of rugby experience within the RUCKAS-YOUTH survey was measured in years, rather than weekly hours, whether this contributed to higher attitude scores remains untested. Whether the safer concussion attitudes stated by private school participants are a result of greater participant awareness of expected contextual norms, or do indeed reflect safer attitudes, remains unknown. The differences between the two groups warrants further investigation as targeted interventions may be indicated.

### 5.4.5 Age and Experience

As with previous studies,(350)(360) no significant differences in overall concussion knowledge or attitude were observed between age groups. This suggests that, as long as appropriately designed for youth cohorts, further age specificity of educational interventions is not indicated. It would also suggest that younger age groups are suitable targets for intervention, as they may carry knowledge through a playing career. Only one significant individual attitude response difference was noted between age groups. A greater proportion of older participants stated they were more likely to put themselves under pressure to return to play whilst symptomatic, than younger participants. In contrast, greater rugby playing experience was associated with safer overall CAI scores. When evaluated collectively, the findings suggest that although rugby experience may heighten awareness of expected norms, increasing age may also heighten intrinsic drive to play. This, again, reflects the conflict experienced by participants between expected behaviour, known risks, and their drive for continued participation. For sport's governing bodies to ensure that safe behaviours result from head injury incidence, influencing the balance between these drivers is essential.

### 5.4.6 Concussion Knowledge and Attitude Associations

No association between total CKI and total CAI was found suggesting that greater concussion knowledge does not directly lead to a proportional increase in concussion attitude safety. Only one knowledge question demonstrated a predictive effect on CAI, 'Symptoms of concussion can last for several weeks'(83.5% ±1.1 correct)(Figure 9) If knowledge of this concussion feature is representative of heightened concussion attitude safety, its inclusion in all concussion education would seem advisable. Higher CKI scores were also associated with safer attitudes within the 'Reporting Norms' and 'Prevention Strategies' attitude themes. This further reinforces the construct that improved knowledge may heighten awareness of what reduces concussion, and what is expected of players post injury, but as no other attitude associations were found, knowledge may not influence intended behaviour.

The lack of association between concussion knowledge and attitude observed supports previous investigations that similarly report no direct link.(352)(353) Several theories as to why have been presented in the literature. Some follow the supposition that decisions made after injury are commonly non-deliberative and thus reactive.(477) Kroshus *et al.*(411) cite confusion as a reason why a participant might not fully consider their actions following a concussion.(411) Similarly, high emotion and arousal during sporting competition has been associated with impulsive decision making.(478) Conversely, participants may be making more cogent choices where the drive for continued play overcomes the known risks.(360) As both elements are contextually influenced, individual, and variable, defining post head injury psycho-social drivers remains challenging. Despite this, the continued search to understanding the decision making that follows head injury, and its miriad influences, is imperative. Qualitative studies that further explore the specific attitudes of youth rugby players towards concussion are clearly warrented. It should also be noted that, despite this study reinforcing the need for targetted concussion attitude change interventions in youth rugby, knowledge gaps still exist. Such knowledge limitations require intervention to ensure that participant decisions, regarldess of influence, are predicated on accurate health information.

### 5.6 Limitations

An inherent limitation of attitude assessment remains the potential gaps that exist between knowledge and behaviour and intention and behaviour.(416) The rise in concussion awareness and, in turn, increasing knowledge of expected norms, may compound this.

Until a practical objective measure of concussion frequency is found which reduces the reliance on symptom reporting, measuring the gaps between predicted and actual behaviour remains challenging. The survey design attempts to mitigate this limitation, but it requires appreciation when interpreting results. The COVID-19 pandemic led to delays in data collection due to prohibited rugby participation. Despite data collection occurring only during competitive match play periods, the impact of prior sporting time loss is unknown. During the data collection period SRC risk reduction evidence has developed. In response, minor amendments may enhance the survey design. Data collection of any specific school policy regarding DBaH conduction would present a clearer appreciation of participant engagement. This would enable a greater understanding of whether the observed participation figures were indeed accurate, or influenced by a lack of DBaH awareness. Similarly, gaining an incite of the value participants place on rugby engagement may further understanding of attitudes towards symptom disclosure. If, as hypothesised, greater participation value promotes less-safe attitudes towards concussion disclosure, behaviour change interventions should be focused on cohorts whom demonstrate greater drive to play. The influence of participation value on disclosure intention requires further review to this end. To further define the impact of rugby experience, particularly in the private school sector, weekly rugby engagement could be sought within the RUCKAS-YOUTH survey.

Further understanding of risk reduction strategies such as neck strengthening may also enhance the survey. It is anticipated that neck strengthening will become a commonly used SRC risk reduction intervention in the future.(196) A baseline of its appreciation would be beneficial in order to compare with future responses. Assessing participant levels of motivation to play and perceived rewards may reveal an association with intended reporting behaviour. If found, intervention strategies could be modified to suit the competitive drive of specific cohorts.

### 5.7 Recommendations for Educational Strategies

As previously documented, the results of this study suggest that appropriate symptom disclosure appears influenced by the level of desire to play balanced against the perceived risks of continued participation.(360) As such, the utility of educational approaches that focus only on deliberative, considered behaviour, may be limited. Future educational strategies should, therefore, focus on addressing knowledge and attitudes that present barriers to appropriate symptom reporting and removal from, and return to play.(331) These include an enhanced awareness of the consequences of concussion, reinforcement that symptom severity is not an indicator of future safety, and that youth players can be more vulnerable to the consequences of concussion than adults. Attitude interventions should be framed around either promoting or reducing the most influential attitudes. This could be through promoting a greater sense of the risks of continued participation to both health and/or team performance, and/or reducing the perceived benefits of continued participation. Consideration should be made to the sporting context such decisions are made in. Education initiatives need to reflect the emotive, impulsive decisions commonly made in sporting environments like rugby. Education scenarios should be as realistic to the experience of the intended recipient as possible. As such, generic multi-sport concussion education programmes should be designed to allow contextual adaptation whilst maintaining evidence-based core features. In addition, greater emphasis should be placed on the benefits of, and engagement with, risk reduction strategies such as GRTP, specific warm-up's and correct tackle technique.

### 5.8 Conclusions

This study has established baseline concussion knowledge and attitudes of UK community youth rugby players. It is the first study to include a large number of female participants, document perceived completion of the RFU DBaH concussion education programme, (16.9%) and assess differences in state and private school attending participants concussion knowledge and attitude. The RUCKAS-YOUTH survey could, therefore, provide a suitable platform from which to assess the efficacy of future concussion education and behaviour change risk reduction interventions within rugby. Reflective of similar SRC research, (360)(367)(369) this study presents no evidence to suggest that a history of previous concussion, engagement in current educational programmes or heightened concussion knowledge, influences youth rugby safety attitudes. Although no overall differences in concussion knowledge and attitude were observed between the sexes, significantly lower attitude safety scores with regard to the consequences of reporting were recorded by male participants. Conversely, greater rugby playing experience was associated with safer overall CAI scores. No significant differences in overall concussion knowledge or attitude were observed between age groups or school attendance, besides private school attending participants reported significantly safer attitudes towards concussion.

This study was gratefully received by the RFU (see appendix D) and provides both a framework for further rugby specific concussion knowledge and attitude assessment and an understanding of current concussion knowledge and attitudes of youth rugby playing cohorts. Such data could be used as a baseline from which to review the efficacy of future risk reduction interventions as indicated by risk reduction frameworks. Further research is required to explore the contextual psycho-social factors that influence young rugby players attitudes and behaviours towards concussion.

# CHAPTER SIX

## 6.0 Discussion

Following individual discussion of each study detailed in the preceding chapters, this section reviews the studies implications on SRC management at both a micro and macro level, set within the research and sporting context of their publication. The chapter concludes by discussing the thesis limitations, future research directions and finishes with the authors' conclusions and personal reflections.

## 6.1 Research Implications in Context

The studies within this thesis have had notable impact. Study One aimed to present a detailed report of concussion incidence within a youth community rugby population. Prior to this research, small scale studies had been published, however methodologies and injury definitions varied.(49)(216) No consensus had been established as to the frequency of either reported or actual concussion incidence for this cohort.(479) At the time of Study One's publication, debate and conjecture surrounding concussion risk at youth rugby levels was high within research communities. In 2016 the Sports Collision Injury Collective, (SCIC) instigated by Newcastle University researchers Allyson Pollock and Graham Kirkwood, led 73 medical and public health signatories in calling on the UK Chief Medical Officer's (UK CMO) to ban tackling and the scrum from state school rugby.(479) This came under the SCIC's vociferous public declaration that all contact should be removed from sport and physical education within the school environment.(480) The press subsequently reported the SCIC's headline "Protect children, remove contact' widely.(481) In response, World Rugby affiliated researchers Ross Tucker, Martin Raftery and Evert Verhagen published a critical review of the evidence cited by the SCIC.(5) This was followed by a rejection of the call to ban tackling by the UK CMO who state that they;

> *"do not feel rugby participation poses an unacceptable risk of harm and could not support any actions that would increase inequalities in participation. We think the benefits of experiencing, learning, training and playing rugby, with appropriate supervision, safety and coaching, considerably outweigh the risks of injury."*(479)

The SCIC responded via publication within the British Journal of Sports Medicine(425) and replied to the UK CMO citing the United Nations Convention on the Rights of the Child (Article 19). This states that governments have a duty to protect children from risks of injury.

The four-season data collection of Study One, therefore, represents the broadest investigation of reported concussion incidence within youth community rugby published to date, and comes at a time of considerable academic and public discourse. The reported concussion incidence rate of 12.7 per 1000 match hours sits far higher than previous concussion incidence rates of 0.2-6.9/1000 match hours cited by SCIC affiliated researchers(216). The figure also sits higher than the RFU's most recent investigation of youth rugby injuries with an concussion incidence rate of 8.7/1000hrs.(13) The figure presented sits closer to the 20/1000hrs reported by Barden and Stokes,(13) the authors of the RFU study, from a sub group of participants competing at the highest level of English school rugby. This figure echo's the highest reported match head injury incidence rate within Study One of 23.1 per 1000 match hours within the U12 age group. This data sets the upper most limits for youth rugby concussion incidence to date(13) and highlights the significance of its publication. The epidemiological results of Study One in combination with the study highlighted above, suggest that reported concussion incidence in UK youth rugby continues to rise. No evidence of the plateau in concussion incidence observed in adult elite rugby is apparent.(4) Despite this, Study One and similar investigations that attempt to control data collection as rigorously as possible, are taking us closer to consensus. It can, therefore, be postulated that concussion incidence at UK youth levels sit between 12.7 and 23 per 1000 match hours. Although still broad and encompassing age grades from 14-18 years, this represents a considerable rise on previous estimates, a rise that mirrors that seen in adult cohorts.(4)

As previously stated, (section 2.5.8) such figures do not directly represent the frequency of head injuries or concussion currently. The figures represent the frequency of the documented, reported head injuries and or symptoms. The true frequency of concussion at youth levels includes reported incidents rates in addition to the currently unknown amount of those that go unobserved or unreported. The results of Study One found that all participants tested post-injury demonstrated submaximal cognitive performance and reported symptoms that would otherwise prompt removal. This implies that 12.7/1000 match hours represented the level of reported concussion incidence and, therefore, the minimum level of true injury prevalence. As observed within elite adult cohorts, continued high quality investigation should see reported incidence rates at youth levels form consensus and plateau if the game laws remain largely unchanged. Objective assessment tools such as saliva testing, video occulography(301) and gum shield accelerometry(112) may accelerate this process, and if used to assess symptomatic and control groups, could define under reporting rates for the first time. Driven closer to defining youth rugby concussion incidence by Study One, key rugby stakeholders are now more informed when attempting to make evidence-based participation decisions.

In addition to providing a detailed and rigorous account of reported concussion incidence in youth community rugby, Study One broke new ground through its novel use of the King-Devick test (K-D). The key finding that relevant baseline improvements were only apparent after two years of aging validates the studies annual baseline collection and could be used to support baseline conduction every two years, further enhancing practicality. Now armed with baseline data collected from every youth player engaged in competitive rugby at the club, the on-site duty therapists had an objective means of gauging the cognitive impact of a suspected head injury. Despite not influencing RTP decisions, which remained governed by World Rugby/RFU protocol's, the staff were able to demonstrate the cognitive effects of a head injury to players and parents. This engaged parents in their child's welfare through repeated home testing demonstrated by the 93.8% parental engagement rate. The process placed an awareness of full cognitive recovery at the forefront of parents return-to-play decision making. These findings also support the RFU's view point that, prior to its comparison to the HIA within English professional rugby,(35)

*“ the K-D Test had the potential to impact beyond the professional game if a validated assessment could be identified that could be performed by a non-medical practitioner.*(35)*”*

Since the publication of Study One, the K-D Test has continued to be used and evaluated in a range of sports and settings.(482-484) Its utility as a validated side-line concussion test has been widely demonstrated and its oculomotor and saccadic foundations are now being used in advanced optic testing.(268) The biggest barrier to its wide-scale use within community level sport appears to be financial. In 2015 King-Devick Technologies Inc. signed a licensing agreement with the Mayo Clinic, one of the largest US health care providing organisations.(485) Access to the test is not freely available to either institutions, clubs or the public, and is now solely tablet based.(486) For community-based sports clubs and states schools that have a fraction of the financial resources of professional sports organisations, cost implications of subscriptions, even those involving player welfare, can present considerable barriers. Currently, no validated free to use oculomotor concussion assessment tool is available to the public. This may be the single most challenging aspect of translating a validated concussion assessment tool from elite levels to grass-roots participation. For an objective concussion assessment tool to achieve wide-scale use it will almost certainly need to be free. Unless governing bodies cover such additional costs, they must ensure that participation in their sport is not restricted further by participants financial resources.

With an enhanced, if not ideal, concussion assessment process in place for the therapists and parents, ensuring suitable referral for medical review became a priority. The primary role of community club Emergency First Aider's (EFA's), a role commonly undertaken by parents, is to be identify, manage, and facilitate further medical assessment when warranted. There had been limited exploration of those who take on the EFA role within community sport and their contribution to concussion management previously. In turn, it was not a role that had been targeted specifically by rugby governing bodies. Without a greater appreciation of these key individuals pitch-side interactions, the symptom reporting process remained poorly understood. If encouraging players to report symptoms is a key pillar to successful community sport risk reduction, EFA's were a primary stakeholder.

Study Two provided a detailed account of EFA demographics and knowledge through the socio-technical framework employed by Clacy *et al.*(1). By converting the questionnaire employed by the researchers into an audio-response recorded format, the practical challenges of participant engagement were overcome. A more conventional qualitative approach such as interviews or focus groups could have been used to explore EFA attitudes further, however, this may have reduced participant numbers and limited the demographic and engagement findings. The results from Study Two suggested EFA's felt highly engaged within concussion management, however post injury referral to a club physiotherapist or medic was suggested by only 12 (30%) of EFA's, whilst only five (12.5%) stated that they would ensure that the player did not RTP that day. Although not the primary goal of the study, the engagement of EFAs and increased understanding of their knowledge/awareness, provided an opportunity for targeted interventions at a local level. Observed knowledge gaps were appropriately addressed during EFA training. limitations of concussion symptom knowledge was targeted with copies of the pocket concussion recognition tool(487) given to all EFA's and coaches.(487) Concussion 'Signs and Symptoms' posters were placed in toilets. Recruitment was focused on female parents whom accounted for 75% of those already in post. In addition, with a newly found appreciation of the role in pitch-side injury observation that female parents played, targeted posters where placed in female toilets. (see figure 6.1 below) The 40% of EFA's that had not previously completed the RFU online concussion resource programme were directed towards doing so. Most importantly, emphasis within EFA training was placed on the risks of RTP post injury and the need for suitable medical referral. These interventions at a club level would almost certainly reflect those required across the wider sporting community.

# Mum's Guide to Concussion

Rugby is a physical game and injuries do occur. From time to time players will get bangs to the head that could be considered 'Concussion'. Here at Cobham we feel the benefits of Rugby for young people far outweigh the risks from injury, however this does not stop us from trying to make the game as safe as possible.

Here is our guide to how you as a MUM can help…

## DON'T…

**Worry** – 80-90% of concussion symptoms resolve in a week without lasting consequences. The risks lie mostly in continued play after sustaining an injury.

**Interrogate** - your child about possible head injuries. Kids often do not report injuries if they think they will be stopped from playing. You want them to be open and honest with you.

**Leave Rugby to your partner** – research suggests Mums and Dads have differing views on the risks and rewards of contact sports. Speak to each other about your thoughts and find a balance between you. Be consistent with your message.

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## Do…

**Watch the game closely** – If you see a player who may have sustained an injury tell the coaches or first aiders. They cannot see everything. You are a vital part of this.

**Ask your child how they think and feel** – During and after rugby talk to your child about the game. How they played, how they feel. You want them to be open and honest with you and to report any injury that has occurred.

**Monitor them closely** – If they have had an injury you are best placed to spot any symptoms. These may include feeling dizzy, slowed down, in a fog, unusually tired.

**Report** – If your child has had a knock at school or elsewhere it is essential you tell your child's coaches. This is the hardest challenge for head injury management.

**Questions or concerns?** – Just ask. The medical team at Cobham are onsite for you and your child. Pop down and see someone in the medical room.

For lots more info on concussion and Cobham Rugby's injury management programme please visit the club website tabs
The Club – Physiotherapy – Concussion
**David Silver MCSP – Lead Physio**

Figure 6.1. Mum's Guide to Concussion Poster (2017) D. Silver

Having received an invitation from the RFU to discuss this thesis, the findings of Studies One and Two were presented. At this time, EFA's did not have dedicated RFU online resources and the RugbySafe Lead role(488), a volunteer designated to lead a clubs EFA's, had yet to be implemented. This role was formalised in 2017/18 designed to help the RFU educate and support EFA's with a particular focus on head injury assessment and treatment through a formal club appointment. Ensuring someone filled this role was built into rugby club governance mandated for RFU affiliate club status. RugbySafe Leaders are now tasked with organising risk assessed first aid and pitch-side care provision, emergency action plans, injury reporting and appropriate training and equipment for EFA's.(488) The findings from Study Two were gratefully received by the RFU and helped inform the development of this key rugby injury prevention and management role.

During discussions with the RFU, it became apparent that a shared desire to obtain a better understanding of youth player knowledge and attitudes towards concussion within rugby was present. The governing body was in the early phases of updating the DBaH online education programme, and as a leading organisation in sports head injury management, hoped that it could form the foundation of multi-sport, nationwide concussion education in time. The current DBaH intervention had not previously been directly informed by participant knowledge limitations or established attitudes. To address this, a greater appreciation of youth player concussion knowledge and attitude would be required. To this end, in conjunction with the RFU a platform was developed that could establish youth concussion knowledge and attitudes. This could then be used to evaluate the content of the DBaH and other future concussion risk reduction interventions efficacy. The findings from Study Three RUCKAS-YOUTH survey were presented to the RFU in late summer 2022. The most notable finding being that heightened player concussion knowledge was not directly associated with safer attitudes. A focus on improving participant knowledge of concussion was, therefore, not enough to change behaviour. As most concussion education, including the DBaH programme, has previously been focused on addressing knowledge deficiencies to improve compliance through symptom awareness, this finding meant that attitude change should be promoted to influence autonomous reporting intention. This bottom up approach(384) to influencing reporting intention should, therefore, be considered a key component of SRC risk reduction at youth levels.(411)(489) This fundamental shift in concussion education focus from knowledge enhancement to attitude change had been previously theorised,(39) but had remained unsubstantiated or instigated by governing bodies. To achieve this in a rugby context, governing bodies would require an understanding of the outcome expectations and risk perceptions that shape participant reporting intention.(490) Study Three has begun to reveal some of the primary attitudes that drive reporting intention. Its key findings support the premise that outcome expectations of symptom disclosure are of prolonged and unnecessary removal from play, which when coupled with perceived high participation reward, can discourage disclosure when decision making is autonomous. As this highlights, the disclosure attitude findings from Study Three appear to fall into either outcome expectations or risk perceptions categories, previously described in section 2.8.4. To promote symptom disclosure, sport's governing bodies could, therefore, attempt to heighten risk perceptions. This approach has been used strikingly within UK smoking cessation campaigns, following the rationale defined by the HBM (see section 2.8) that if risk perceptions outweigh perceived benefits of participation, safer decisions will ensue.(328) However, unlike smoking, which can result in negative health outcomes, sports participation carries arguably greater biopsychosocial benefits. Heightening perceived risks could, therefore, threaten wider sporting engagement and associated benefits. Against a backdrop of broadly falling rugby participation, balancing risk awareness with participation promotion would appear a very complex governance issue. Health risks cannot be side-lined by unbridled promotion of the game, nor can risks be emphasised at the expense of participation promotion. As a result, such messaging decisions are challenging. The current paucity of risk data at youth levels compounds matters further, and as risk perceptions are viewed as one of the least influential predictors of health behaviour,(416) promoting what are still not fully known risks would seem flawed.

If emphasising health risks to encourage symptom disclosure lacks merit, other avenues of tipping the risk versus reward decision scales might be considered. Lowering the intrinsic drive for continued participation may appear challenging, but means could be found. As Study Three confirms, current mandated stand-down periods following suspicion of concussion appear a distinct barrier to symptom disclosure. If top-down(384) means of modifying the GRTP process that individualises stand-down periods, whilst continuing to mitigate risks is found, participants may be more encouraged to report symptoms. To do so, physical and cognitive recovery must be established through validated means. As Study One reported, the K-D Test was used to establish cognitive recovery to this end. It could be a key element in a multimodal assessment to individualise a GRTP time period. Many barriers to implementing such a process exist and may prove hard to overcome. The pioneering advances in oculomotor function and saliva testing may make this goal more achievable at elite levels and a trickle down to community grades may follow if these tests help further validate practical, accessible tools like the K-D Test.

In addition to addressing the barriers that participation exclusion presents, other avenues for disclosure promotion may exist. If participant attitudes towards the health risks of continued play do not supersede the drive to remain engaged, damaging the team's collective performance might. Governing bodies could promote how continued participation not only increases personal risk, but may also negatively impact the team through diminished performance.(371) Rather than benefiting the team, poor performance through missed tackles, dropped passes, poor decision making etc., could be highlighted. As well as the participant, such messaging could be focused on coaches and EFA's, who's potential impact on concussion knowledge and attitudes were highlighted in studies Two and Three. They could be instrumental in demonstrating the negative consequences of non-disclosure on team performance. Another potential avenue for concussion education intervention highlighted by Study Three could be the promotion of, and adherence to, risk reduction strategies. Study Three reported mixed appreciation of strategies that may reduce concussion risks, particularly the potential positive impact of injury prevention movement programmes and limited capabilities of protective equipment. Improving player awareness of what does and does not mitigate concussion risks could be achieved directly through education and indirectly via key stakeholders such as coaches and EFA's. Such interventions would benefit from the underpinning frameworks of health behaviour change models such as the HAPA and Van Mechelen

Principles(420)(490)(see section 2.8) which are ideally suited towards injury prevention programme adherence.

Armed with three studies addressing a lack of youth concussion prevalence data, the efficacy of novel assessments, and key stakeholder knowledge and attitude understanding, alongside literature review insights, the findings and recommendations (see appendix E) were presented to the RFU. As a result, the RFU extended an invitation to the author to consult on the subsequent redesign of the DBaH resources. With the intention to be directed by the RUCKAS-YOUTH and thesis findings, the updated DBaH programme will have a greater attitude change focus with its impact validated by continued RUCKAS-YOUTH assessment. This represents considerable real-world impact for both the study and thesis, exceeding expectations. Using the RUCKAS-YOUTH Survey to this end has enabled the cyclical function of injury prevention models to be completed Not only has it been used to establish limitations in concussion knowledge and attitude that can be targeted by intervention, it presents a means to then assess the efficacy of the interventions selected. If the survey continues to be used in this way and evolve as the game changes, interventions can be directed to ensure they meet the ongoing safety needs of the sports participants.

As with the RUCKAS-YOUTH survey, the wider thesis has used the defining features of the Van Mechelen principles, to guide its journey. Each of the three studies have helped define the extent of concussion risk within youth rugby, particularly the epidemiological findings established in Study One. The broad and detailed literature review has then revealed the current evidence base as to the aetiology and mechanisms of concussion in youth rugby. Novel interventions including the K-D Test, EFA educational material, and finally the RUCKAS-YOUTH Survey, have been introduced. The circle has been closed by the survey's ability to assess the efficacy of current and future educational risk reduction interventions.

### 6.2 Thesis Limitations

Due to the ever growing and high-profile nature of concussion research, it is a field with considerable scope for scientific exploration. As a result, one of the hardest aspects of this thesis was to ensure that it provided considerable depth of investigation whilst maximising its broad potential for real-world impact, all whilst remaining ground-breaking throughout its long duration. As a result, the three study areas were defined through impact potential over a focus on one isolated field. This would reflect the multi-faceted and holistic approach cited as essential features of successful concussion risk reduction.(422) This approach would only prove successful if each study carried rigorous methodological design and significant practical application. As such, a limitation of this thesis could be considered its lack of area focus. This is, however, a limitation minimised by the collective impact of the three studies reported, an impact unlikely to have resulted from narrower study aspirations. This thesis does not address the growing need for research on the long-term effects of head injuries and concussion that starts with youth participation. Such research is much needed as this will certainly become a primary concern for participants and governing bodies. Developments within the measurement of sub-concussive and asymptomatic injury events will be required to fully establish risks. Similarly, this thesis did not evaluate the specific interventions that may become key risk reduction interventions in the future. Greater emphasis on these might have provided baseline youth attitudes towards such interventions as neck strength and substitution limits for example, if incorporated within Study Three.

### 6.3 Future Directions

In March 2021 the UK Government's Digital, Culture, Media and Sport Committee (DCSM) began a review of concussion in sport. It's stated aims were to consider scientific evidence for links between head trauma and dementia and to determine how risks could be mitigated. The committee would take evidence on the implications for youth sport, funding for further scientific research, and the role of national governing bodies in ensuring member clubs receive up to date medical advice and promote best practice. During the summer of 2021 the committee called for written evidence and published oral transcripts from leading head injury expert depositions. Appendix C contains written evidence submitted by myself and supervisors that was published by the committee. The submission details my experiences of managing concussion at community rugby levels and the rationale for this thesis. It provided an opportunity to frame both my clinical and research experiences and describe future directions that could enhance head injury assessment, management and risk reduction interventions. The committee have published three reports to date with the final report containing proposals expected in late summer 2022. The committee's previous publications have highlighted several areas that require intervention to address a long-term failure to reduce the risks of brain injury in sports.(491) These include a lack of a unified, coherent concussion approach across sports and nations, limitations within NHS concussion management, a paucity of long-term head injury research and unstructured grassroots support. With reference to the need for ongoing research, the third report cites Professor Willie Stewart, a prominent neuropathologist and leading head injury expert, who states that;

> *"well-designed, focused studies that are directly towards answering application questions and do it with robust methodology are incredibly important, but they are few and far between in this field".*(491)

In addition, the committee emphasise the need for independent research to negate the confirmation bias they associate with governing body funded investigations. This criticism is extended to the Concussion in Sport Group (CISG) discussed in section 2.6.3, whose work the report suggests is an ultra-conservative perspective emanating from a group of researchers significantly funded by sporting governing bodies.(491) With consideration to the collaborative nature of Study Three, it is pleasing to recognise that no external funding was sought for this thesis, and, in turn, no editorial pressure was experienced. As the report suggests, this type of research is both unusual and much needed.

In formal response to the committee's initial reports, the government has already agreed to a UK protocol for concussion across all sports with all four nations developing a shared set of protocols, based on the current Scottish model.(491) This model has employed a coherent concussion risk reduction programme across all grassroots sports in Scotland, whereas elsewhere in the UK, each sport governing body has designed and implemented its own concussion interventions. This should provide much needed consistency if underpinned by evidence-based interventions and consistent validation, defined within injury prevention models. (see section 2.8.1) Until the final report is published, the key details and recommendations remain unknown. What can be predicted is heightened legislative engagement in protecting sports players of all levels from the long and short-term risks associated with head injuries. High quality research will, therefore, remain essential.

The research developments called for above will certainly impact elite levels first. The pioneering biomarker work of Birmingham University discussed in section 2.6, for example, could have considerable impact over the coming years. Even if saliva testing cannot be brought widely to pitch-sides at community levels due to financial constraints, the understanding gleaned from investigations incorporating its use could be profound. Not only could it provide far greater accuracy to concussion incidence levels, it could help validate other cost free, practical tools. Similarly, developments in video occulography (see section 2.6.4) that use smart phone technology, underpinned by saccadic research as used by the K-D Test in Study One, may begin to provide grass roots stakeholders with the means to objectively define concussion. These two developments, alongside ongoing research using gumshield accelerometry (see section 2.3.2) should lead to notable progress in concussion assessment at all levels. Concussion management could also be enhanced if improvements in objective assessments are made. If testing of concussion becomes easier and more accurate, tailoring individualised concussion GRTP as discussed above, could become possible. Repeated home testing as employed in Study One, could be used to define when GRTP stages can begin, negating the need for mandated stand-down periods. If such information is shared between organisations and stakeholders as suggested by the DCMS report,(491) another barrier to safe return to play could be reduced. Concussion management will be influenced by burgeoning research into the long-term effects of concussion and sub-concussive events. Continued improvements in biomarker and imaging techniques should present a better understanding of the long-term consequences of head injuries. As a result, threshold limits for sub concussive events could be presented to protect the long-term health of participants. Accelerometry advances may provide the means to determine such levels.

Further research could also build on the novel evaluation of EFA's within Study Two. With their influence and characteristics now defined, exploring ways in which this key role could be enhanced to improve concussion assessment and management can be achieved. This could have implications for other sports that could similarly benefit from individuals with concussion specific skill sets. Building on the findings of Study Three and those of a similar nature, future research is required to evaluate behaviour change interventions, a clear focus for concussion risk reduction, designed to address the breadth of cultural and social norms and attitudes that influence stakeholder choices. Evolution of the RUCKAS-YOUTH survey in line with the changing landscape of concussion understanding, could facilitate this and maintain its utility. This may negate the commonly time dependant nature of previous knowledge and attitude assessments. One prominent concussion attitude that warrants enhanced research is the barriers to injury disclosure. Study Three furthered understanding greatly in this area but it requires continued rugby specific review and the most impactful mediums of intervention must be established. Once found, the most effective frequency of such interventions requires assessment. Risk reduction interventions naturally evolve and so this process requires constant appraisal. Regardless of the direction that concussion risk reduction interventions take, they must be underpinned by the appraisal structures incorporated into frameworks such as Intervention Mapping (IM) discussed in section 2.8.1.4. This will ensure their efficacy is reviewed, amended when required, and remain evidence based.

Further research could also continue to define the most effective top-down means for concussion risk reduction within youth rugby. The most prominent being the nature of tackle contacts, specifically the height/body level at which a tackler is permitted to engage with a ball carrier. High quality research is required to substantiate the efficacy of the chosen law amendments, and as importantly, continue to monitor their effects, as directed by all risk reduction frameworks (see section 1.2.5). As important as identifying and appraising the most impactful interventions will be fostering the greatest stakeholder engagement. If players, coaches and volunteers feel disenfranchised by perceivably autocratic instruction, both player safety and participation may be dangerously reduced. This will only be negated if those involved in grass roots rugby feel a sense of utility and ownership over shaping the collective evolution of the game.

Aside from the continual appraisal of in-game rule changes, improvements in neck strength and proprioception have emerged as leading risk reduction interventions. (see section 2.8.6) To date, no research has been published that specifically evaluates a neck strengthening protocol for youth rugby participants and its potential impact on concussion risk. If established, neck strength and proprioception drills could become a directed intervention for pre-training and match play at all levels. As with tackle height changes, heightened stakeholder educational engagement could provide the ideal platform from which to foster the player and coach engagement these type of intervention depend upon.

### 6.4 Personal Reflections

The conduction of this thesis has been the backdrop to half of my working life. It was born from my own workplace challenges described above. Not only have I been critiquing the meal, I have been developing the menu, cooking it, eating it, and doing the washing up! As such, I have lived and breathed its development both theoretically and literally. On commencement I had no idea that it would take nearly a decade to complete. During this time, I would get married, have two amazing children, nearly die, walk alongside friends and family experiencing cancer, and a host of other remarkable life events. My career would develop considerably and I would benefit from so many remarkable mentors. It is hard to fathom how I could grow from barely one A level to the edge of a PhD without such encouragement and support. I owe so much to the sacrifices of so many, and could write another thesis describing the profound impact they, and this work, has had on me. In many ways I have been very lucky. The study period saw an explosion of concussion awareness and research, all whilst I was at the coalface of concussion investigation and management. To be in the thick of such a fast moving and ground-breaking field has been thrilling. To be engaged by the RFU to help direct future developments has given my work what I had hoped for, genuinely positive impact, rather than becoming a dust-collecting tome. To be considered a valued figure with the potential to influence youth rugby safety, even in the smallest way, gives me great pride. What has not changed in this time is my passion for the transformative capacity of movement and sport, especially rugby. Coupled with an endlessly inquisitive mind, I have found a field that gives me a sense of complete purpose. Never has this work felt a chore as I have stuck strictly to my parent's mantra 'It doesn't matter what you do, just do something you enjoy'. As with any meaningful enterprise, this feels far from the end and more like the start. I look forward to opening the next door on the journey.

### 6.5 Conclusions

There remains a considerable amount of investigative work required to fully define the risks that head injuries present within rugby at community youth levels. Study One has furthered understanding in this field by establishing youth community rugby reported concussion incidence rates and the utility of the K-D Test in this arena. Despite requiring similar high-quality investigations to achieve consensus, defining youth rugby head injury risk is becoming a thoroughly achievable aim. Study One also presented a framework to create individualised GRTP programmes that may negate the challenges mandatory stand-down periods create. Continued concussion assessment developments that build on the work presented in this thesis may make this achievable in the short to mid-term. The role of key stakeholders in promoting the benefits of physical activities like rugby, and ensuring the wellbeing of young participants, will remain central to community sport risk reduction.  As identified in Study Two, a key stakeholder within youth rugby are EFAs. This previously under recognised role could facilitate enhanced concussion recognition, acute management, and suitable referral. The RFU have now placed this key role under the direction of a mandated club First Aid Co-Ordinator within the affiliated club governance structure. Solidifying the importance of this role can only enhance rugby safety.  Similarly, Study Three provided the most detailed appreciation of the knowledge and attitudes of the most impactful stakeholder on concussion risk, the participants themselves. The data recorded has become integral to the development of risk reduction education interventions designed to enhance concussion knowledge and promote safer attitudes of young participants. I hope to assist in this process alongside the sports leaders to this end. If, however, rugby players of all ages are still not purposefully engaging in safety education which risks their and other players health, consideration must be made to making such participation mandatory. If RFU affiliated status were to depend on concussion safety education completion for all stakeholders, including players, a far higher level of influence could be achieved. In line with sports risk reduction frameworks, this process should also include an intervention appraisal such as the RUCKAS survey, in order to close the loop and provide ongoing efficacy appraisal and education modification directives.

Alongside an ever-growing canon of concussion research, this thesis and its constituent studies should not be expected to establish the safety of rugby or any sporting activity. Safety is an intrinsically subjective assessment. Rigorous investigation is required only to present the clearest appreciation of the risks and how best to mitigate them. When the question, 'what are the concussion risks involved in community youth rugby?' can finally be answered by the scientific community, parents, players, and all those involved, will have evidence to support their participation decisions. The judgment of, 'are the risks acceptable?', can then be made collectively between the games governing bodies and its stakeholders. This process requires continuous collaboration and an open forum for which to determine a unified and widely accepted path towards heightened safety. If this is not achieved, disenfranchisement may occur compromising safety and risking further declines in sporting participation. To this end, I hope to utilise the findings of this thesis and future research involvement to add as much value as possible to the continued evolution of rugby, and to support its patrons in shaping the game of the future.

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**Appendix A – Study Two Questions**

St Mary's University Twickenham London

## THE QUESTIONS YOU WERE ASKED ARE LISTED BELOW

**1. Are you?**

**1. Are you a parent of a player?**

**2. What age group(s) do you support?**

**3. How often do you attend Rugby matches as a First Aider?**

**4. Have you attended a first aid course / hold a first aid certificate?**

**5. If so, was it rugby/sport specific?**

**6. Have you had any concussion specific education?**

**7. If YES what sort?**

**8. Have you completed any part of the RFU HEADCASE online concussion awareness program?**

**8. Do you feel you have had a sufficient education for your role as a team First Aider?**

**9. If NO, why not?**

**10. Where would you go first for more information/guidance on concussion?**

**10. Do you feel you have a role in concussion PREVENTION?**

**11. If so how would/do you actively prevent concussion?**

**12. Do you feel able to IDENTIFY concussion?**

**13. What symptoms would you expect to observe in a concussed player?**

**14. What questions would/do you ask a player you suspect has concussion?**

**15. Are you involved in TREATING concussion?**

**16. If so how would/do you treat concussion?**

**17. If you removed a player from the field what further action would/do you take?**

## Appendix B – RUCKAS-YOUTH Survey

# RUGBY UNION CONCUSSION KNOWLEDGE AND ATTITUDE SURVEY (RUCKAS - YOUTH)

St Mary's University
Twickenham
London

RFU

Rugby Football Union
Rugby House, Twickenham Stadium
200 Whitton Road, Twickenham TW2 7BA
T: 0871 222 2120 F: 020 8892 9816
englandrugby.com

**PARTICIPANT INFORMATION SHEET**

RUGBY UNION CONCUSSION KNOWLEDGE AND ATTITUDE SURVEY
(RUCKAS-YOUTH)

As part of PhD research, David Silver MCSP - St. Mary's University Twickenham and the Rugby Football Union (RFU) have developed a survey to gain a greater understanding of the thoughts of young Rugby players regarding concussion. The information gained will be used to help direct education initiatives to make the game as safe as possible.

**Invitation**
You are invited to take part in this study as you are a youth Club or School Rugby Union player. Your participation is voluntary and anonymous. Your initials and date of birth are only recorded to allow withdrawal at a later date. You are free to withdraw your consent and discontinue participation before March 1st 2022 by completing the withdrawal form in your documents pack. This will not influence any present and/or future involvement in research. You will be notifed by email when the withdrawal process has been completed.

**The Survey**
The survey will take 10-15 minutes to complete. This will be done either online or on paper, at your School or Club. The survey is divided into three sections; About you, Concussion Knowledge and Concussion Attitudes. Once completed, your data will be combined with that of other players to gain a greater understanding of Rugby concussion knowledge and attitudes. It may then be used by David Silver/RFU for further ongoing comparison.

**Participation**
If you agree to participate please sign the consent form and complete the survey. By doing so you agree that you have not received any coercion or inducement to participate in this survey from Teachers, Coaches or Researchers.

**PLEASE NOW COMPLETE THE CONSENT FORM**

YOU WILL BE GIVEN A COPIES OF THESE FORMS TO KEEP

David Silver BSc MSc MCSP – Lead Researcher - St. Mary's University, Twickenham
Cobham Sports Association, Cobham, Surrey, KT11 2BU 081302@live.stmarys.ac.uk 07793650569

RUGBY UNION CONCUSSION KNOWLEDGE AND ATTITUDE SURVEY
(RUCKAS-YOUTH)

**CONSENT FORM**

INITIALS______________________________DATE OF BIRTH______________________

SCHOOL_______________________________________________________________

Title of study:
RUGBY UNION CONCUSSION KNOWLEDGE AND ATTITUDE SURVEY (RUCKAS-YOUTH)
Lead Researcher: D. Silver St. Mary's University, Twickenham, London.
081302@live.stmarys.ac.uk 077936 50569

Members of the research team: N. Brown, S. Patterson

1. I agree to take part in the above research and I have read the Participant Information Sheet which. I understand my role in this research and I have had any questions answered to my satisfaction.
2. I understand that I am free to withdraw from the research before 1/3/2022, for any reason and without prejudice.
3. I have been informed that the confidentiality of the information I provide will be safeguarded.
4. I am free to ask any questions at any time before and during the study.
5. I have been provided with a copy of this form and the Participant Information Sheet.

Data Protection: I agree to the University processing personal data which I have supplied. I agree to the processing of such data for any purposes connected with the research project as outlined to me.

Signed………………..…………………………………………… Date…………………………......

YOUR PARTICIPANT ID CODE ________________________________________

St Mary's University Twickenham London

**RUGBY UNION CONCUSSION KNOWLEDGE AND ATTITUDE SURVEY**

RFU

Please complete this survey as honestly as possible. If you have any questions, please call your Coach/Teacher or Researcher to you. Your answers will be used to help make Rugby Union as safe as possible.

**I have read the information sheet and signed the consent form** Y ☐ N ☐

---

**1 Are You?** (Please tick)

Male ☐ Female ☐

**2 For how many years have you been playing Rugby Union?** (Please tick)

0 - 3 ☐ 4 - 6 ☐ 7 - 9 ☐ 10 - 12 ☐ 13 - 15 ☐

**3 Have you ever completed the RFU *'Don't Be a HEADCASE'* online module?** (Please tick)

Yes ☐ No ☐

**4 If 'YES' when was the last time you completed it?** (Please tick)

This year/season ☐ Last year/season ☐ 2 years/seasons ago ☐

**5 Have you received any other concussion education/guidelines from;**

(You may tick more than one box, leave blank if none received)

School Teacher/Coach ☐ Physiotherapist ☐

Rugby Club Coach ☐ School Nurse or Medical Staff ☐

Doctor ☐ Seen on TV/Social Media ☐

Friend/Teammate ☐ Parents ☐

**6 Do you think you have had concussion in the past?** (Please tick <u>one</u> box)

No ☐ Yes, once ☐ Yes, twice ☐ Yes, three times or more ☐

## Concussion Knowledge

This section is designed to gain a better understanding of your knowledge of concussion within Rugby. Please attempt to answer all questions.

**7 Who is recommended to perform a medical review/assessment of a player before a return to contact based Rugby following concussion?** (please tick <u>one</u> box)

Teacher / Coach ☐ Nurse / Physio ☐ GP / Doctor ☐ The Player ☐

Parents ☐

**8** **Below is a list of statements, Please tick if they are TRUE or FALSE;**

| | | T | F |
|---|---|---|---|
| a) | You have to be 'knocked out/unconscious' to be concussed | | |
| b) | Concussions can only occur from a hit to the head | | |
| c) | Young people are at greater risk of concussion than adults | | |
| d) | Weightlifting helps to build muscle | | |
| e) | During Rugby you are more likely to be injured if you are still recovering from a previous concussion | | |
| f) | There is a possible risk of death if a second concussion occurs before the first has resolved | | |
| g) | Studs can help to grip the playing surface | | |
| h) | Concussion is as serious as other injuries | | |
| i) | Symptoms of concussion can last for several weeks | | |
| j) | After 10 days symptoms of concussion are usually gone | | |
| k) | Although symptoms may resolve quickly, the brain may not have fully recovered after concussion | | |
| l) | Playing on whilst suffering from a concussion can lead to serious health consequences | | |
| m) | After a concussion, your emotions (anger, sadness etc.) can change quickly and intensely | | |

**9** **Which of the following players would you say might be "concussed "?**
(You may tick more than one box)

a) After a big knock/fall/head clash the player starts to make wrong decisions or actions during the game ☐

b) A teammate is complaining of headaches and has "blurred vision" ☐

c) After a ruck/fall/head clash a player is left on the ground not moving ☐

d) A player complains of stinging or burning in his calf muscles ☐

e) In the changing room a couple of hours after the game, a teammate complains of feeling sick, with a headache (player has not been drinking alcohol) ☐

**10** **Of the following, what are the possible complications of receiving a second head injury when still concussed?** (You may tick more than one box)

a) No complications exist ☐

b) Increased symptoms ☐

c) Increased risk of further injury ☐

d) Brain damage ☐

e) Memory problems ☐

f) Joint problems ☐

g) Second Impact Syndrome ☐

h) Impaired performance, (e.g. missed tackles, dropped balls etc.) ☐

**11** **Please tick the following statements you consider to be a SIGN or SYMPTOM of concussion.** (You may tick more than one box)

| | | | | | |
|---|---|---|---|---|---|
| a) | Abnormal sense of smell | ☐ | j) | Headache | ☐ |
| b) | Difficulty remembering | ☐ | k) | Difficulty Sleeping | ☐ |
| c) | Blurred vision | ☐ | l) | Loss of consciousness | ☐ |
| d) | Black eye | ☐ | m) | Nausea | ☐ |
| e) | Bleeding from the ear | ☐ | n) | Numbness or tingling of the arms | ☐ |
| f) | Bleeding from the mouth | ☐ | o) | Skin rash | ☐ |
| g) | Bleeding from the nose | ☐ | p) | Sharp burning pain in the neck | ☐ |
| h) | Confusion | ☐ | q) | Weakness in neck movements | ☐ |
| i) | Fever | ☐ | r) | Dizziness | ☐ |

**12** **How long is the recommended minimum relative rest period following concussion for both adults and youth rugby players, before a graded return to play can start?** (please tick one box)

5 days ☐ 7 days ☐ 14 days ☐

19 days ☐ 23 days ☐

**Concussion Attitude**

This section is designed to gain a better understanding of your attitudes towards concussion within Rugby. Please answer all questions as honestly as possible.

**13** **Please rate how strongly you AGREE or DISAGREE with the statements below by circling a number;**

| | | *Strongly Disagree* | *Disagree* | *Neutral* | *Agree* | *Strongly Agree* |
|---|---|---|---|---|---|---|
| a) | Understanding concussion is important as a rugby player | 1 | 2 | 3 | 4 | 5 |
| b) | Tackle technique is important in preventing concussion | 1 | 2 | 3 | 4 | 5 |
| c) | Head guards and gums shields reduce the risk of concussion | 1 | 2 | 3 | 4 | 5 |
| d) | A suitable warm up reduces the risk of concussion | 1 | 2 | 3 | 4 | 5 |

**14** **Please rate how strongly you AGREE or DISAGREE with the statements below by circling a number;**

| | | *Strongly Disagree* | *Disagree* | *Neutral* | *Agree* | *Strongly Agree* |
|---|---|---|---|---|---|---|
| a) | If I report what I suspect might be a concussion, I will hurt my team's performance | 1 | 2 | 3 | 4 | 5 |
| b) | If I report what I suspect might be a concussion, I will not be allowed to start playing or training when I think I'm ready | 1 | 2 | 3 | 4 | 5 |
| c) | If I report what I suspect might be a concussion, I will lose my spot in the team | 1 | 2 | 3 | 4 | 5 |
| d) | If I report what I suspect might be a concussion, my teammates will think less of me | 1 | 2 | 3 | 4 | 5 |
| e) | If I report what I suspect might be a concussion, I will be held out of games even if its not a concussion | 1 | 2 | 3 | 4 | 5 |

**15** **Please rate how strongly you AGREE or DISAGREE with the statements below by circling a number;**

***"I would stop playing and report my symptoms if I sustained an impact that caused me to…"***

| | | *Strongly Disagree* | *Disagree* | *Neutral* | *Agree* | *Strongly Agree* |
|---|---|---|---|---|---|---|
| a) | See stars | 1 | 2 | 3 | 4 | 5 |
| b) | Vomit or feel nauseous | 1 | 2 | 3 | 4 | 5 |
| c) | Have a hard time remembering things | 1 | 2 | 3 | 4 | 5 |
| d) | Have problems concentrating on the task at hand | 1 | 2 | 3 | 4 | 5 |
| e) | Feel sensitive to light or noise | 1 | 2 | 3 | 4 | 5 |
| f) | Have a headache | 1 | 2 | 3 | 4 | 5 |

**15 Continued**

| ***"I would stop playing and report my symptoms if I sustained an impact that caused me to…"*** | *Strongly Disagree* | *Disagree* | *Neutral* | *Agree* | *Strongly Agree* |
|---|---|---|---|---|---|
| g) Experience dizziness or balance problems | 1 | 2 | 3 | 4 | 5 |
| h) Feel sleepy or in a fog | 1 | 2 | 3 | 4 | 5 |

**16 Please read the following scenarios and circle how strongly you AGREE or DISAGREE with the statements below;**

| **Scenario 1.** *The Fullback experienced a concussion during the first gam of the season. The flanker experienced a concussion of the same severity during the cup semi-final game. Both players had persisting symptoms…* | *Strongly Disagree* | *Disagree* | *Neutral* | *Agree* | *Strongly Agree* |
|---|---|---|---|---|---|
| a) Most players would feel that the Full Back should have returned to playing during the first game of the season. | 1 | 2 | 3 | 4 | 5 |
| b) My teammates would feel that the Full Back should have returned to playing during the first game of the season. | 1 | 2 | 3 | 4 | 5 |
| c) Most players would feel that the Flanker should have returned to playing during the cup semi-final game. | 1 | 2 | 3 | 4 | 5 |
| d) My teammates would feel that the Flanker should have returned to playing during the cup semi-final game. | 1 | 2 | 3 | 4 | 5 |

| **Scenario 2.** *The Prop experiences a concussion during a game. The Coach decides to keep the Prop out of the game. The Prop's team loses the game.* | *Strongly Disagre* | *Disagree* | *Neutral* | *Agree* | *Strongly Agree* |
|---|---|---|---|---|---|
| a) My teammates would feel that the Coach made the right decision to keep the Prop out of the game. | 1 | 2 | 3 | 4 | 5 |
| b) Most players would feel that the Coach made the right decision to keep the Prop out of the game. | 1 | 2 | 3 | 4 | 5 |

| **Scenario 3.** *The Winger experiences a concussion. The Winger's team has a Physio pitchside...* | *Strongly Disagree* | *Disagree* | *Neutral* | *Agree* | *Strongly Agree* |
|---|---|---|---|---|---|
| a) My teammates would feel that the Physio, rather than the Winger, should make the decision about the Winger returning to play. | 1 | 2 | 3 | 4 | 5 |
| b) Most players would feel that the Physio, rather than the Winger, should make the decision about the Winger returning to play. | 1 | 2 | 3 | 4 | 5 |

**Scenario 4.**

A Rugby Sevens player experienced a concussion and has a game later in the day. They are still experiencing symptoms of concussion. However, the player knows that if he tells his Coach about the symptoms, his Coach will keep him out of the game.

| | *Strongly Disagree* | *Disagree* | *Neutral* | *Agree* | *Strongly Agree* |
|---|---|---|---|---|---|
| a) My teammates would feel that the player should tell his Coach about the symptoms. | 1 | 2 | 3 | 4 | 5 |
| b) Most players would feel that the player should tell his Coach about the symptoms. | 1 | 2 | 3 | 4 | 5 |
| c) My teammates would continue playing while also having a headache that resulted from a minor concussion. | 1 | 2 | 3 | 4 | 5 |
| d) Most players would continue playing while also having a headache that resulted from a minor concussion. | 1 | 2 | 3 | 4 | 5 |

**17** **Please rate how strongly you AGREE or DISAGREE with the statements below by circling a number;**

| | *Strongly Disagree* | *Disagree* | *Neutral* | *Agree* | *Strongly Agree* |
|---|---|---|---|---|---|
| a) If all of the symptoms of concussion have gone, you can safely return to contact Rugby. | 1 | 2 | 3 | 4 | 5 |
| b) I have put myself under pressure to play when I am still experiancing symptoms of concussion. | 1 | 2 | 3 | 4 | 5 |
| c) I have been put under pressure by a Coach or Teacher to play when I am still experiancing symptoms of concussion. | 1 | 2 | 3 | 4 | 5 |
| d) I have been put under pressure by my Parent/Guardian to play when I am still experiencing symptoms of concussion. | 1 | 2 | 3 | 4 | 5 |
| e) I have been put under pressure by a teammate(s) to play when I am still experiencing symptoms of concussion. | 1 | 2 | 3 | 4 | 5 |

## SURVEY COMPLETED - THANK YOU

PLEASE PLACE IT BACK IN THE ENVELOPE AND **MARK A CROSS IN THE BOX.**

# Appendix C – DCSM Written Evidence

**UK Parliament - Digital, Culture, Media and Sport Committee (DCSM)**

**Concussion in Sport Inquiry**

**Written evidence submitted by David Silver MCSP, with Dr Nicola Brown & Dr Stephen Patterson (St Mary's University, Twickenham)**

1. My Name is David Silver MCSP and I have spent the last eight years leading PhD concussion research at St. Mary's University Twickenham within youth community Rugby Union. This has culminated in a research collaboration with the Rugby Football Union (RFU) to help validate and direct concussion education and behaviour change programmes.

2. As a youth sports Physiotherapist for over 15 years, and latterly a concussion consultant, I have worked with countless head injury patients and attempted to both assess and manage the consequences.

3. When I embarked on this career, player, parent and coach understanding of concussion was poor, as was the general public's appreciation of its impact. I, and my colleagues, struggled with impractical and unsubstantiated assessment tools, wide-scale under-reporting of symptoms and next to no specific evidence base from which to make informed clinical decisions.

4. Parents would be left without substantive advice, coaches lacking awareness would make key decisions and in hindsight, player health was often put at risk. Despite the challenges this presented to those charged with welfare, this was the norm reflected across the Rugby world.

5. Many things have changed in the intervening years as exposure of head injury management in sport has risen dramatically. High profile cases at the elite level and tragically, avoidable,

youth deaths have brought into sharp focus one of the greatest threats to sporting participation.

6. Heightened public attention has also driven a rise in academic investigation. The resultant growth in evidence has begun to shape our understanding of both the pathophysiological and behavioural features and how best to assess and treat concussion. Despite these positive steps, many considerable gaps in knowledge remain.

7. The majority of investigation to date has focused on elite level players. However, participation at community levels represents the overwhelmingly larger population, of which young players represent the majority. The impact of concussions on these cohorts is far less documented.

8. The resultant lack of youth concussion understanding is heightened by the acceptance that young people are more likely to sustain concussion,(9) experience symptoms for longer,(10) and can suffer 'Second Impact syndrome' with potentially fatal consequences.(11) Young players therefore represent the most vulnerable playing population in the UK and worldwide.

9. This dearth of evidence and the challenge it presents to parents, coaches and medics motivated me to embark on research attempting to make the game I love, safer for young players.

10. To address the lack of epidemiological understanding within youth community Rugby and to trial the novel use of an assessment tool, my colleagues and I undertook four years of data collection from 489 8–18-year-olds. The investigation titled 'Reported concussion incidence in youth community Rugby Union and parental assessment of post head injury cognitive recovery using the King-Devick test' was published by the Journal of Neurological Sciences in 2018.(12)

11. The publication represents the largest investigation of reported head injury incidence in youth UK Rugby Union to date. The observed match related head injury incidence of 12.7 per 1000 match hours (95% CI 9.2 – 17.5) was considerably higher than that of previously published studies.(5)(6)

12. Since this publication, the concussion research community has moved closer to establishing consensus on the risks of concussion that elite level Rugby presents. This has not been the case at community and youth levels where ambiguity remains.

13. Several barriers have hampered establishing this key metric; The lack of practical, pitch-side concussion diagnostic tools at community levels leaves its diagnosis shrouded in uncertainty.(7)(8) Assessment, therefore, remains a primarily subjective process. This places great pressure on those conducting assessments when asked to form a binary diagnosis. As a result, the term 'suspicion' of concussive symptoms has become the basis for removal from play.(9) With no objective pitch-side diagnostic tools, those responsible for the welfare of players at grass roots levels have little to substantiate decisions.

14. This challenge is compounded by the reliance on player symptom reporting. Unlike elite levels where multiple match officials and video replays can be employed, head injury recognition at community levels relies heavily upon player reporting.
15. Under-reporting of concussion symptoms has been a consistent barrier to risk reduction across a range of sports and levels.(10) The risks of under reporting are heightened in contact sports as second impact syndrome has been linked to fatal consequences, and the long-term effects of repeated concussion remain poorly defined. Understanding of the drivers behind concussion reporting is growing, but this complex psychosocial research field is in its infancy. Greater research is, therefore, required to direct effective risk reduction strategies.

16. Risk reduction strategies have been employed by all major Rugby playing nations under the guidance of World Rugby, the games global governing body. Such strategies have commonly been based on educating players and key stakeholders to bridge a perceived gap in understanding.(11) To establish the efficacy of such interventions, researchers commonly first establish the injury risk, administer the intervention, and then monitor for change in injury frequency.(12) Due to the limitations in concussion assessment and the reliance on symptom reporting in community rugby noted above, this method is flawed. (Fig.1 below) Indeed, if concussion awareness or behaviour change interventions are successful, reported injury rates may increase.

Figure 1. The inter-dependant barriers to improved concussion risk reduction within community level sports.


17. To mitigate the challenges within community level Rugby that poorly defined injury risk presents, such as a barrier to conventional risk intervention evaluation, other ways of assessing intervention effectiveness are required. Without this, risk reduction remains unsubstantiated and potentially ineffective.

18. To this end, St Mary's University, Twickenham and the RFU have collaborated to develop the Rugby Union Concussion Knowledge and Attitude Survey (RUCKAS). The survey presents a means of gaining pre- and post-intervention information that can then be used to direct future risk reduction strategies. Despite the inevitable ill-defined gap between stated intentions and actual behaviour, specifically designed surveys of this nature present the most practical means of gauging efficacy when injury incidence rates are unsettled. It is hoped

that the youth community Rugby player understanding gained can then inform the content of concussion risk reduction strategies the RFU delivers.

19. In order to make rugby as safe as possible continued high-level research is essential. It is, therefore, pleasing to see the RFU and World Rugby encouraging and collaborating with independent research groups like mine to this end. When research reveals a clearer understanding of the short and long-term risks that sports related head injuries present, players, parents' coaches and all those who appreciate the benefits of sports like rugby, can make truly informed decisions. In addition, continued investment in research driven assessment, management and education programmes that are commonly sport specific, could be standardised across governing bodies. This would reduce ambiguity for parents, coaches, teachers and participants and ensure continuity of best practice. We hope this enquiry will highlight some of the challenges described above and reveal future interventions that may protect participants whilst promoting the wellbeing sport undoubtedly delivers.

We thank you for the opportunity to contribute to this inquiry. Should the Committee have any questions about this submission or require any further information, please contact: David Silver. athenaphysio@gmail.com

Yours sincerely,

David Silver BSc (hons) MSc MCSP - St. Mary's University, Twickenham
*25th March 2021*

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## Appendix D – RFU Citation

*Support Statement for David Silver*

*On behalf of the Rugby Football Union I would like to offer my support and endorsement to David Silver in regards to the completion of his PhD research and thesis submission.*

*We engaged with David in the 2018/19 season, since then we have continued to work together and collaborate to collate insight and data to gain understanding on the use and impact of the HEADCASE concussion awareness programme and related resources.*

*David has led and directed his research and continued to persist with data collection during very challenging times (throughout the COVID-19 pandemic). The output of his research now provides us with a robust and valuable baselines and evidence base. Access to this insight has given us the understanding to develop the HEADCASE programme and specific resources to increase it's effectiveness, and to advance his research to further increase our understanding of what impact our education resources have and the impact they have in changing behaviour and attitudes as well as providing knowledge.*

*I'd like to take this opportunity to thank and congratulate David on his research, I'm grateful for the opportunity to collaborate with him and the opportunity that this insight now provides.*

Rachel Faull-Brown

RFU Player Welfare Manager

## Appendix E - RUCKAS-YOUTH 2022 Findings Summary

- Stated DBaHC completion is low.
- Private school participants are significantly more likely to report DBaHC completion.
- DBaHC does not appear to influence either CKI or CAI.
- No observed differences in concussion knowledge between State and Private school participants was found.
- Private school attending participants demonstrated significantly safer concussion attitude scores.
- Age does not appear to influence either concussion knowledge or attitude, therefore, as long as appropriately designed for youth cohorts, further specificity of educational intervention is not indicated.
- Greater experience is associated with increased concussion attitude safety.
- Overall, concussion knowledge was reflective of current adult cohorts and higher than previously reported youth cohorts.
- Participants commonly state that understanding concussion is essential as a rugby player.
- Youth rugby players are largely aware of the signs and symptoms of concussion in a rugby context. Concussion awareness is, therefore, an unlikely driver of non-reporting behaviour.
- Understanding of the consequences of concussion is poor.
- Appreciation of appropriate GRTP is poor.
- A large percentage of youth rugby players are unaware that they are at greater risk of concussion than adults.
- A quarter of participants were not aware that there is a possible risk of death if a second impact occurs before the first has resolved.

- Overall concussion attitude is equal to that of adult cohorts and has improved over time.

- Most players know that tackle technique is important in reducing concussion.

- Most players incorrectly feel gumshields and headguards may prevent concussion.

- Players are not that aware of how appropriate warm-ups can reduce concussion risk.

- Players are more likely to disclose observable symptoms and disclosure behaviour may be linked to perceived symptom severity.

- Players cite placing more pressure on themselves to return to play than from external sources.

- Being held out of games is the most prominent driver behind symptom non-disclosure.

- The only knowledge predictor of concussion attitude is knowing that ‘symptoms of concussion can last for several weeks”.

- No significant difference in reported attitudes between ‘Most’ and ‘My teammates’ suggesting that self-predictive behaviour is commensurate with social norms.

- No overall difference in CKI/CAI was observed between the sexes.

- Females scored significantly less safe than males when stating that ‘If all the symptoms of concussion have gone, you can safely return to contact rugby’.

- Lower female rugby experience and less previous concussion history were the only broad points of difference between the sexes. They do not impact CKI/CAI.

- Males showed significantly lower attitude safety towards the consequences of symptom reporting than females.

- Older participants were significantly more likely to state they put themselves under more pressure to return to play whilst symptomatic than younger participants.

**Key Messaging**

- CONCUSSION CAN LAST FOR SEVERAL WEEKS
- THIS IS WHAT CONCUSSION FEELS LIKE
- YOUNG BRAINS ARE MORE VULNERABLE
- THIS IS WHATS GOING ON IN YOUR BRAIN AFTER A HEAD INJURY
- NO SUCH THING AS A MILD CONCUSSION
- CONTINUED PLAY CAN HURT YOUR TEAM
- A SECOND IMPACT COULD KILL
- PLAYING WITH SYMPTOMS COULD KILL
- SUITABLE WARM-UPS REDUCE CONCUSSION RISKS
- GUMSHIELDS AND HEADGUARDS DON'T STOP CONCUSSION
- EVEN WHEN SYMPTOM FREE YOUR BRAIN MAY NOT HAVE HEALED
- YOU CAN HURT YOUR TEAMS PERFORMANCE IF YOU CARRY ON PLAYING
- YOU WILL NOT LOOSE YOUR TEAM PLACE IF YOU REPORT CONCUSSION
- WE LOOK OUT FOR EACH OTHER -HAVE COLLECTIVE RESPONSES

# The Challenges of Concussion Assessment, Management and Education within UK Youth Community Rugby Union

**October 2022**