MPHIL

DEVELOPING, IMPLEMENTING AND EVALUATING A SMARTPHONE APPLICATION FOR REMOTE-ATHLETE MONITORING AND INJURY SURVEILLANCE IN ACADEMY RUGBY UNION

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ABSTRACT

A major barrier to evidence-based safety and performance decision-making in sport is the availability of longitudinal, high-quality data. This is particularly relevant to remote-athlete talent pathways in sports such as Rugby Union, where both the operation of these pathways and a comparatively high injury-risk has attracted considerable public scrutiny. Consequently, this research was undertaken to investigate reducing barriers to remote-athlete monitoring and injury surveillance practices within English academy rugby union.

The first study of this thesis documents the systematic processes that led to identifying an innovations solution (smartphone application-based athlete monitoring and injury surveillance system), and the development of an intervention (EPD App) and implementation strategy (TDP Project). The second study evaluates implementation impact of these developments using metrics of participant-use (RE-AIM Framework) and perceived-quality (uMARS questionnaire) across nine academies, 999 athletes, over 21-months. Findings showed the EPD App and TDP Project positively impacted the initial Reach (96%) and Adoption (78%) usage, however this did not translate to Implementation (29%) and Maintenance (12%) usage. Above average perceived-quality metrics from the uMARS questionnaire relating to ‘Functionality’ and ‘Ease of Use’, together with a multi-level, context-driven implementation strategy is suggested as contributing to the positive Reach and Adoption usage. Low ratings for ‘Entertainment’, together with socio-environmental factors are suggested as contributing to the poor Implementation and Maintenance. Athletes perceived to have improved their ‘Awareness’ and ‘Knowledge’ relating to managing workloads, wellbeing and injury-risk after using the EPD App, pointing to self-regulation benefits of engaging in self-reporting practices.

This thesis steps out the processes in order to develop, evaluate and innovate athlete monitoring and injury surveillance systems. Novel implementation science tools are applied to detail changes in participant-use and perceived-quality that progress research knowledge. The study demonstrates how barriers to remote-athlete data capture can be reduced by applying context-driven, multi-level development processes and blended scientific designs. Further enhancements and future studies can consider focusing on 1) addressing socio-environmental contexts, 2) facilitating engagement factors, and 3) exploring the self-regulation benefits of self-report monitoring and surveillance systems.

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Table of Contents

1 CHAPTER ONE 11

1.1 INTRODUCTION 11

1.2 RESEARCH CONTEXT 13

1.3 RESEARCH QUESTIONS 17

1.4 THESIS OUTLINE 18

1.4.1 Chapter Two: A Review of the Literature 18

1.4.2 Chapter Three: Exploring the development and implementation process of a bespoke smartphone application for athlete monitoring and injury surveillance in academy rugby union. 18

1.4.3 Chapter Four: Evaluating the development and implementation of a bespoke self-report athlete monitoring and injury surveillance smartphone application in academy rugby union 18

1.4.4 Chapter Five: General Discussion, Applied Applications and Future Directions 19

2 CHAPTER TWO 20

2.1 FOUNDATIONS OF ATHLETE MONITORING AND INJURY SURVEILLANCE 20

2.2 INVESTIGATING SPORTS PERFORMANCE 21

2.3 INVESTIGATING SPORTS INJURY 23

2.4 ATHLETE MONITORING AND INJURY PREVENTION MODELS 25

2.4.1 General Adaption Syndrome Model 25

2.4.2 Principles of Sports Training 27

2.4.3 A Dynamic, Recursive Model of Injury Aetiology in Sport 27

2.4.4 A Workload Model of Physical Performance and Injury in Sport 29

2.4.5 Psychosocial Model of Sports Injury 30

2.4.6 The Athlete Monitoring Cycle 32

2.4.7 The Sequence of Prevention 34

2.4.8 Translating Research into Injury Prevention Practice (TRIPP) Framework 35

2.4.9 A Risk Management Framework for Sports Related Injuries 37

2.4.10 Complex Adaptive Systems Theory 38

2.4.11 Summary of Foundations of Athlete Monitoring and Injury Prevention: *40*

2.5 Biopsychosocial Approaches to Athlete Monitoring and Injury Surveillance 42

2.5.1 Terminology and Definitions *42*

2.5.2 Summary of Terminology and Definitions: *43*

2.6 Quantifying Load-Response-Injury Interactions 45

2.6.1 Sources of Athlete Load *45*

2.6.2 Step 1: Quantifying Athlete Load *47*

2.6.3 Step 2: Monitoring the Athlete's Response to Load *48*

2.6.4 Step 3: Injury Surveillance *50*

2.6.5 Summary of Quantifying Load-Response-Injury Interactions: *57*

2.7 Capturing Remote-Athlete Biopsychosocial Load-Response-Injury Data 58

2.7.1 Self-Report Measures *58*

2.7.2 Session-RPE Load *59*

2.7.3 Wellbeing and Life Stress Questionnaires *62*

2.7.4 Oslo Sports Trauma Research Centre Questionnaire *68*

2.7.5 Mobile Athlete Self-Report Methods – Smartphone Applications *70*

2.7.6 Summary of Capturing Remote-Athlete Biopsychosocial Load-Response-Injury Data: *72*

2.8 Developing and Evaluating Sporting Implementation Strategies 74

2.8.1 Understanding the Context *74*

2.8.2 A Six-Step Intervention Development Process *76*

2.8.3 The RE-AIM Evaluation Framework *79*

2.8.4 The User Mobile Application Rating Scale *81*

2.8.5 Summary of Developing and Evaluating Sporting Implementation Strategies: *83*

2.9 Rationale for Current Research 84

3 CHAPTER THREE 87

3.1 Introduction 87

3.2 Methods 90

3.3 Results 92

3.3.1 Contextual Foundations and Literature Review ... *92*

3.3.2 Consulting with Experts ... *95*

3.3.3 Engaging the End-User ... *97*

3.3.4 Design and Testing of the Intervention and Implementation Strategy ... *99*

3.4 Discussion ... 114

3.5 Conclusion ... 119

4 CHAPTER FOUR ... 121

4.1 Introduction ... 121

4.1.1 Study Aims: ... *123*

4.2 Methods ... 124

4.2.1 Design ... *124*

4.2.2 Cohort ... *125*

4.2.3 Intervention ... *125*

4.2.4 Implementation Procedures ... *126*

4.2.5 Evaluation Procedures ... *126*

4.2.6 Data Analysis ... *129*

4.3 Results ... 131

4.3.1 RE-AIM Framework Evaluation ... *131*

4.3.2 uMARS Evaluation ... *133*

4.4 Discussion ... 137

4.5 Limitations ... 145

4.6 Conclusion ... 146

5 CHAPTER FIVE ... 147

5.1 Introduction ... 147

5.2 Addressing the Research Questions ... 148

5.3 Original Contribution to Knowledge ... 154

5.4 Practical Implications and Potential Impact ... 154

5.5 FUTURE DIRECTIONS 157

5.6 THESIS CONCLUSION 159

6 REFERENCES 161

7 APPENDICES 178

7.1 ACADEMY PRACTITIONER WORKSHOP SURVEY 178

7.2 ACADEMY BRIEFING DOCUMENT 179

7.3 PLAYER CONSENT EXAMPLE 183

7.4 EPD APP REGISTRATION AND USER GUIDES 187

7.5 ACADEMY AND PLAYER EDUCATION WORKSHOPS 193

7.6 EXAMPLE FEEDBACK CHANNELS 198

7.7 uMARS CONSENT AND SURVEY 199

List of Figures

Figure 1: General Adaptation Syndrome Model proposed by Selye (1950) 26

Figure 2: A Dynamic, Recursive Model of Injury Aetiology in Sport developed by (Meeuwisse, Tyreman et al. 2007) 28

Figure 3: Workload Injury Aetiology in Sport Model proposed by (Windt and Gabbett 2017) 30

Figure 4: A Model of Stress and Athletic Injury proposed by Andersen and Williams (1988) with updates by Williams and Andersen (1998) 31

Figure 5: The Athlete Monitoring Cycle proposed by Gabbett, Nassis et al. (2017) 33

Figure 6: The Sequence of Prevention Model developed by van Mechelen, Hlobil et al. (1992) 35

Figure 7: Translating Research into Injury Prevention Practice (TRIPP) Model developed by Finch (2006) 36

Figure 8: A Risk Management Framework for Sports (Fuller and Drawer 2004) 38

Figure 9: A depiction of the 'web of determinants' within a complex system for ACL injury-risk where (A) refers to a Baseball player and (B) a Ballet Dancer by Bittencourt, Meeuwisse et al. (2016) 39

Figure 10: Illustration of the applied Athlete Monitoring and Injury Surveillance Definitions and Terminology for this Thesis 44

Figure 11: Common Athlete Load Monitoring Quantification Methods summarised by Bourdon, Cardinale et al. (2017) 48

Figure 12: Common Athlete Response Monitoring Quantification Methods summarised by Bourdon, Cardinale et al. (2017) 50

Figure 13: Session Rating of Perceived Exertion Scale developed by Foster, Florhaug et al. (2001) 60

Figure 14: Subjective Wellbeing Problems Questionnaire developed by McLean, Coutts et al. (2010) 67

Figure 15: OSTRC Questionnaire example questions for the Knee developed by Clarsen, Myklebust et al. (2013) 69

Figure 16: A Six-Step Intervention Process for Sport proposed by Donaldson, Lloyd et al. (2016) 77

Figure 17: Operationalised Intervention Mapping process used by Donaldson, Lloyd et al. (2017) 79

Figure 18: Sports-specific adaption of the RE-AIM Framework by Finch and Donaldson (2010) 80

Figure 19: Elite Player Development (EPD) App User Flow 101

Figure 20: Elite Player Development (EPD) App home page 102

Figure 21: Subjective Wellbeing Questionnaire developed by McLean, Coutts et al. (2010) 103

Figure 22: Session-RPE Load Survey – 1) Activity Type 104

Figure 23: Session-RPE Load Survey – 2) Rate of Perceived Exertion intensity rating 104

Figure 24: Session-RPE Load Survey – 3) Activity duration and comments.. 105

Figure 25: Life Stress Survey 106

Figure 26: Performance Restriction Questionnaire (Example for the Knee) (Clarsen, Myklebust et al. 2013) 107

Figure 27: Squad Availability and Academy-Level analysis visualisation from the EPD App 108

Figure 28: Individual athlete adherence and analysis visualisation from EPD App 109

Figure 29: Individual Player Activities Log from the EPD App 109

Figure 30: Weekly academy report 113

Figure 31: Player-level RE-AIM Framework Evaluation with Reach a percentage of total registered players and Adoption, Implementation and Maintenance as percentages of Reach 132

Figure 32: Description of Player EPD App usage as a percentage of the total players that completed the uMARS Evaluation (n =186). 134

Figure 33: Mean, Standard Deviation and Median EPD App Objective Quality Scores by Question (questions 6-16) from the uMARS assessment 135

Figure 34: Mean, Standard Deviation and Median EPD App Educational Value Scores by Question from the uMARS assessment (Questions 21-26) 136

List of Tables

Table 1: Sources of Load from Professional Rugby Union Players proposed by Quarrie, Raftery et al. (2017) 45

Table 2: Existing Injury Surveillance Projects in Sport 51

Table 3: Six-Step Development Process proposed by (Donaldson, Lloyd et al. 2016) used to develop an athlete monitoring and injury surveillance smartphone application in English academy rugby union 90

Table 4: Summary of Research Context into English Academy Rugby Union 93

Table 5: Summary of Literature Review into Remote-Athlete Monitoring and Injury Surveillance 94

Table 6: A blended, staged approach to steps 2 and 3 of the Six Step Development Process 95

Table 7: End-user barriers and modifications made to the athlete monitoring and injury surveillance App throughout the season-1 Pilot. 98

Table 8: The intervention developed, and the implementation and evaluation strategy proposed resulting from Steps 1-3 of the Six-Step Development Process 100

Table 9: Study Design 124

Table 10: The contextualised RE-AIM Framework. 127

Table 11: RE-AIM Framework Evaluation 131

Table 12: EPD App uMARS Objective and Subjective Quality Scores by Section and Overall, out of 5 135

1 CHAPTER ONE

1.1 Introduction

Sport represents one of the most popular and polarising forms of human activity and entertainment. A record 3.6-billion people, almost half of the world's population, are said to have watched the most recent Olympics in 2018 and the global sports market is set to reach 626-billion US dollars by 2023 (NDP Group 2019). Through this engagement and exposure, sport is recognised as an important vehicle for improving broader global health, wellbeing and social mobility. The World Health Organisation places the engagement and participation in sport as fundamental to its 2018-30 global action plan to promote and improve physical activity levels (Foster, Shilton et al. 2018). Professional sports and governing bodies have also become more holistic sources of employment, education, specialist support and for some, wide-ranging commercial opportunity (WHO 2019). Given sport's place in society and the many positive influences it provides, research into optimising participant performance and safety through the monitoring and surveillance of sports participation is of particular interest and benefit.

The capture of high-quality, longitudinal data on the individual, group and contextual levels are integral to improving safety and performance practices. Two of the most widely used sports injury research frameworks, the Translating Research into Injury Prevention Practice (TRIPP) (Finch 2006), and the Sequence of Prevention of Sports Injuries (van Mechelen, Hlobil et al. 1992) are both initially guided by epidemiological and etiologic data, sourced through 'injury surveillance' practices. It is also accepted that the ongoing collection and analysis of athlete biopsychosocial data, termed 'athlete monitoring', forms a fundamental role in individual readiness and sports performance practices (Gabbett, Nassis et al. 2017). The challenge, however, is that capturing and managing this data is especially difficult for a large proportion of the sporting landscape. Many sports and their practitioners are limited by a combination of resource, expertise, technology and access barriers (Bolling, van Mechelen et al. 2018). Furthermore, there is limited applied research documenting the processes behind systematically developing practical, context-specific and scalable sporting data collection, monitoring and long-term surveillance solutions utilising modern technologies (Burgess 2017, Gabbett, Nassis et al. 2017). This lack of evidence-based insight serves as a major barrier, but also opportunity for sporting innovation, and is of particular relevance to athlete development pathways.

Athlete development pathways effectively encompass, the participation and progression of athletes from novice, to life-long senior level engagement and/or expertise in sport (Baker, Wattie et al. 2019). These systems are fluid, and therefore participants enter, leave, progress or remain at a particular stage according to their ability, maturation, dedication, opportunity and personal circumstances/interests (Gulbin, Croser et al. 2013). This means that athlete development pathways serve as an important environment for both developing the next generation of sporting champions, as well as long-term sports participation and physical activity levels. The challenge with managing high-quality, longitudinal data and information insights in these pathways is that the majority of athletes, coaches and key stakeholders are not situated in the same place. The most challenging intersection of an athlete development pathway can be considered during adolescence. This is because adolescence (10 to 19-years of age), represents the greatest movement and diversity inside and outside the pathways. A combination of unique and differing maturation levels, talent selection strategies, multi-sport/club, school and social commitments, as well as a particularly large cohort of participants are all contributing factors (Malina, Rogol et al. 2015). As such, many athlete development pathways are characterised by a distribution of participants, at varying stages, in various locations, across a multitude of different sports and schedules, which spread resources and infrastructure thin. While adolescence represents a sensitive time for personal data access, security and consent, these formative years are also considered fundamentally important to life-long engagement in health-promoting behaviour, safety and performance (Gulbin, Croser et al. 2013, Edwards, Bryant et al. 2017, Foster, Shilton et al. 2018). If we are to inform long-term best practice performance and injury-risk management strategies for all sports, it is pertinent research explore innovative ways to capture high-quality data and information insights from adolescent remote-athletes.

1.2 Research Context

Rugby union is a sport played by 15 players on each side (or 7 in the condensed version of the game) where the aim is to touch down a ball over the oppositions line or kick it over a cross-bar between two posts (Till and Jones 2015). The games last for eighty minutes (senior) and seventy minutes (junior <18yrs) split over two equal halves (Till and Jones 2015). Players can pass the ball to team mates (only laterally or backwards) or run and kick in any direction, while players without the ball can tackle and wrestle in order to regain possession (Till and Jones 2015). Since the game's professionalisation in 1995 it has seen exponential global growth (Harris and Wise 2011). As of 2016, rugby union was being played in 121 countries by 8.5 million people (World Rugby 2017). A record 857-million people watched the 2019 Rugby World Cup, making it second only to the Football/Soccer World Cup in terms of a single sport's popularity (Rugby World Cup 2020)

Rugby Union is a collision sport and therefore while participation in sports such as rugby union provide many positive influences on health there is also the risk of injury (Griffin, Panagodage Perera et al. 2020). Given the physical nature of rugby union, the injury-risk is considered as one of the highest among organised team sport with 87 injuries per 1000 player-match-hours at the professional level (West, Starling et al. 2020), 77 per 1000 player-match-hours at the elite school-boy level (Barden 2018), and 47 per 1000 player-match-hours at the academy level (Palmer-Green, Stokes et al. 2013, Williams, Trewartha et al. 2013, Barden 2018). In the most recent systematic review of injury in rugby union by Viviers, Viljoen et al. (2018), researchers compared existing epidemiological data across different age groups, levels of play, and sex to identify gaps in the literature for future research to consider. While the authors posit that a true comparison is difficult due to both the methodological (study design, definitions used) and contextual (facilities, resources, exposure) differences between ages and levels of rugby union, overall, a decrease in injury-risk with decreasing age (e.g. senior to junior) and level of play (e.g. professional to amateur) was surmised. The exception to this however could be within academy players (16 – 18-years) whereby a melding of both professionalism and young bodies is apparent. The risk of injury at the academy level has been suggested as being 47 per 1000 player-match-hours; 95% CI 39-57 (Palmer-Green, Stokes et al. 2013) however, a more recent epidemiological study on elite school-boy rugby in England, of which many of the regional academy players play in, found an injury risk far higher and closer to senior professional rates (77 per 1000 player-match-hours; 95% CI) (Barden 2018). This suggests that academy rugby union injury rates could be even higher than previously reported, especially given the only study on this cohort (Palmer-Green, Stokes et al. 2013) was collected more than 10-years ago. In England specifically, injury surveillance projects have been operating within the professional (Williams, Trewartha et al. 2016) and community game (Roberts, Trewartha et al. 2017) as far back as 2002 together with a range of bespoke athlete monitoring practices (West, Williams et al. 2019). There are, however, only two studies detailing exposure and injury information within England Rugby's regional academy system (Palmer-Green, Stokes et al. 2013, Palmer-Green, Stokes et al. 2015). The regional academy system predominantly operates as a remote-athlete development pathway, and this has been suggested as one of the major barriers behind the lack of high-quality, longitudinal monitoring and surveillance data (Trewartha and Stokes 2015, Phibbs, Jones et al. 2018).

The English academy system is made up of 14 regional academies, each being aligned to a senior professional club, and funded by the governing body for rugby union in England, the Rugby Football Union (RFU) (RFU 2018). The academies each have a designated, geographic area in which to select athletes between the ages of 14 and 18-years (RFU 2018). These athletes are rarely centrally located, instead, either training and playing at their local schools or clubs and/or travelling from around the region to different academy training centres (Phibbs 2017). While participating at the highest level of rugby union in the country for their age, these players will also participate in multiple sub-levels of rugby (school, local club and county) and age-grade international events (Phibbs 2017). Research shows youth and academy athletes not only participate in multiple levels of their main sport, but also numerous other sports, physical education classes, un-organised play, academic and social commitments (Malisoux, Frisch et al. 2013, Gabbett, Whyte et al. 2014, Hartwig, Del Pozo-Cruz et al. 2019). This places a huge energy and fatigue cost, which is only enhanced by the complex physiological and psychological maturation at play during this period of development (Malina, Rogol et al. 2015). To manage performance outcomes without increasing the risk of injury for these athletes, a sophisticated balance must be kept between the demands asked of athletes and adequate recovery and adaptation (Windt and Gabbett 2017). While promising, the research to date only captures snapshots of the exposures, responses and injury-risk profiles of academy rugby union athletes.

Recent research by Phibbs and colleagues has begun to unpack the busy nature of academy rugby union. Their first study detailed the level of within and between player variation in weekly training exposure across academy, school and amateur club environments (Phibbs, Jones et al. 2017). The researchers described weekly training exposure using measures of total distance, session rate of perceived exertion load (Session-RPE Load) (activity duration in minutes multiplied by a rating of perceived exertion to give an arbitrary unit) and PlayerLoad (an accumulated accelerations metric giving an arbitrary unit). Phibbs, Jones et al. (2017) findings showed within-player week-to-week training exposure to vary by an approximate 30% coefficient of variation (CV) across all measures. The CV helps describe the dispersion of scores, in this case training exposures, around the mean exposure as a percentage. This is to compare the variability of measures with different units and scales e.g. session-RPE and PlayerLoad. When comparing players exposure levels to each other however (between-players), variations ranged between 5% and 84% (CV). This suggested that not only did individual players experience week-to-week variations compared to their own average, but that this average could be vastly different compared to another player in the same group. This could be related to the remote-athlete status of these athletes whereby they come from different schools and club environments within the region meaning they may also have different schedules and demands. This poses several questions surrounding the organisation and structure of academy rugby union players' schedules, but still does not complete the picture due to the lack of competition/match-play exposure and other non-rugby related stressors. The same group therefore followed this research with another study that included rugby training and match-play exposure (Phibbs, Jones et al. 2018). The second study used Session-RPE Load as the sole measure and found similar within-player (CV of 37%) and between-player (CV of 10%) variations in total weekly load (Phibbs, Jones et al. 2018) to their previous study. When rugby match-play was analysed separately, a within-player variation of 96% (CV) was however observed. This was attributed to the fact players were sometimes exposed to no match-play one week and then up to three the following week (Phibbs, Jones et al. 2018). It is not considered uncommon for adolescent rugby union players to be exposed to match-play variations like this given the similar findings of several other studies (Hartwig, Naughton et al. 2008, Hartwig, Naughton et al. 2011, Phibbs, Jones et al. 2017). Also, of interest from this second study was the addition of gym-based and a 'any other activity' session-RPE Load. Average weekly Gym (379 ± 269 standard deviation (SD)) was second only to Rugby Training (662 ± 465) in terms of contribution to total load and while Other Activity provided the lowest contribution (120 ± 195) the within-player CV of these loads was the highest (138%). The additional findings from Phibbs, Jones et al. (2018) provide greater context as to the range of activities and their contributions to the previously described weekly within, and between player variations in overall exposure. Both studies findings suggest that the organisation and structure of academy rugby union players weekly schedules is volatile. Together with the presumption that further academic and social demands exist, the researchers described it as 'organised chaos' (Phibbs, Jones et al. 2018).

While the depiction of 'organised chaos' to describe Phibbs and colleagues' specific findings is conceivable, several limitations exist. Both studies used twenty players between the ages of 16 and 18-years, from the same academy setting, over 10 and 14-weeks respectively. The applicability of these findings to other regional academies and lower age levels therefore is unclear. It is also not certain whether the findings from both studies came from over lapping datasets, and potentially the same players. This is because both studies were from the same research group within the same period of the season with no mention of the year the data was collected. The impact of this could be a far smaller dataset and period of examination, meaning both a less representative insight and issues relating to the distinct comparability and/or associations across the studies. What cannot be questioned however is the lack of similar research designs on this population. To date, both studies represent the only research to examine the academy rugby union system and the variability of activity types and exposures. This knowledge is imperative to the systematic planning and management of these players development (Phibbs, Jones et al. 2018). Given academy rugby union players remote whereabouts, increasingly diverse training and competition habits, and the many number of stakeholders responsible for their development (e.g. parents, school, club, academy, international), practitioners and researchers have found it increasingly difficult to capture longitudinal, large-scale data on these players. The inability to practically monitor academy players and capture longitudinal injury surveillance data could therefore be masking a growing problem whereby these athletes are risking their health and reducing their development opportunities for later life.

The first step in addressing an injury prevention problem is understanding the context and epidemiological factors at play (Finch and Staines 2017). This is achieved through high quality data collection and insights from athlete monitoring and injury surveillance practices. Remote-athlete development pathways such as academy rugby union represent a particularly influential, yet vulnerable cohort. Academy athletes are uniquely placed to influence general sporting participation rates and support driving best practices by providing aspirational examples to other peers and junior levels. They are also the critical component to any talent pathway producing future professional players and thus have a substantial legacy impact on a sport. Yet these athletes are also at the centrepiece of concerning injury-risk trends and a lack of overall data to support informed decision-making and preventative practices. This thesis therefore aims to investigate reducing the barriers to capturing exposure and injury data from this highly influential cohort. The results of this program of work may be of interest to I both rugby and non-rugby sporting stakeholders looking to inform their athlete monitoring and surveillance practices. Findings from this work may aid sports, schools and practitioners in approaching the design and evaluation of bespoke athlete monitoring and injury surveillance systems and strategies while providing insight into the facilitators and barriers to adoption and implementation of such innovations.

1.3 Research Questions

The following research questions will be addressed as part of this thesis:

i. Considering the current sports performance and injury research, what are the viable options to capturing remote-athlete monitoring and injury surveillance data?
ii. Are there evidence-based approaches to planning and evaluating the design and implementation of bespoke athlete monitoring and injury surveillance strategies?
iii. What are the processes involved in developing a bespoke, multi-squad, athlete monitoring and injury surveillance system and implementation strategy in academy rugby union?
iv. How can measures of participant-use and perceived-quality be employed to systematically evaluate athlete monitoring and injury surveillance system innovations?
v. What are the development and implementation considerations when employing a smartphone application-based athlete monitoring and injury surveillance system in academy rugby union?

1.4 Thesis Outline

1.4.1 Chapter Two: A Review of the Literature

Chapter two provides a contextual background for the ensuing experimental chapters of this thesis. The chapter reviews current sports performance research, existing models of athlete monitoring and injury prevention, and the relevance to athlete development pathway data in academy rugby union. Following this context, a review of the current evidence-based approaches to capturing data from remote-athletes for athlete monitoring and injury surveillance purposes is provided together with research frameworks in which to evaluate the viability of such strategies in practice. Objectives in this chapter are to outline relevant athlete monitoring and injury surveillance learnings to remote-athlete settings and provide viable options to capturing academy rugby union exposure and injury data together with the means in which to evaluate these strategies.

1.4.2 Chapter Three: Exploring the development and implementation process of a bespoke smartphone application for athlete monitoring and injury surveillance in academy rugby union.

The aim of Chapter Three is to retrospectively describe the processes involved in developing a bespoke athlete monitoring and injury surveillance system using a smartphone application and the strategy to implement this innovation. Findings from this explorative study will help researchers and practitioners better understand potential avenues to developing their own innovations and strategies, as well as inform the reader of the key smartphone application design features and research methods used for the proceeding evaluation study.

1.4.3 Chapter Four: Evaluating the development and implementation of a bespoke self-report athlete monitoring and injury surveillance smartphone application in academy rugby union

The aim of Chapter Four was to evaluate the athlete monitoring and injury surveillance smartphone application and its associated implementation strategy developed in Chapter Three by reporting on both player-use and perceived-quality metrics. Findings from this evaluation study detail the acceptability of the smartphone application and associated strategy while informing future implementation and innovations.

1.4.4 Chapter Five: General Discussion, Applied Applications and Future Directions

Chapter Five synthesises the key findings of each chapter and summarises the main implications stemming from this thesis by answering the research questions posed in section 1.3. The generalisability and application of the research findings to both rugby, and other sport's remote-athlete development pathways are evaluated. Finally, the key considerations in delivering similar research in the future, and potential approaches to further both the applied and academic fields in this area are discussed.

2 CHAPTER TWO

A Literature Review into Developing, Evaluating and Innovating Athlete Monitoring and Injury Surveillance for Remote-Athlete Data Capture

2.1 Foundations of Athlete Monitoring and Injury Surveillance

Sport has evolved from games for pure entertainment and leisure to a competitive, professionalised industry with growing event and commercial demands (Bucur, Macovei et al. 2016). Inherent to sports growth, and more demanding competitive programs, sporting stakeholders face increasingly greater pressure to stay competitive. As a result, athletes and their support staff push boundaries to improve performance but must also mitigate risk through sound injury management practices (Soligard, Schwellnus et al. 2016). Principles of performance and injury management are therefore cornerstones of any sport's athletic ambition, welfare practice, commercial reach and the basis of investigations into what data to collect and how. Understanding the basis of sports performance and injury management is therefore the starting point for this thesis. Performance management can be defined as the 'continuing process of identifying, measuring and developing the performance of individuals and teams, and aligning performance with the strategic goals of the organisation' (Aguinis, Gottfredson et al. 2013). This component of sport allows for the systematic and cohesive integration of sporting strategy, operations, culture and practice. To ensure athletes are safe, healthy and available to perform, injury management is also of peak concern. Sports injury research broadly refers to the systematic approach to understanding and ultimately preventing undue damage or harm during sports participation (Verhagen and Van Mechelen 2010). Before preventative measures can be researched, the field of sports injury research utilises a branch of medicine termed 'epidemiology', that is specifically concerned with how often, and why, health related events occur in human populations (Rose and Barker 1978). Epidemiological research proposes the notion, that a health-related event (in this case injury) does not occur purely by chance, but is the result of interrelated factors that we can identify, track and potentially manage (Bahr, Engebretsen et al. 2009). Both performance and injury management are based around measuring and understanding these interrelated factors to improve athlete performance and safety outcomes. Therefore, building investigations into athlete monitoring and injury surveillance practices requires firstly an overview of sports performance and injury research.

2.2 Investigating Sports Performance

There is a growing global trend for large investments by government institutions and private corporations in sports performance and athlete development pathways. These investments are focused on succeeding not only in the sporting arena but also the financial markets (Cardinale 2017). Over a 5-year period a reported $10.3-billion US dollars were spent across public universities in the United States to fund their sports programs according to an examination from the Huffington Post and The Chronicle of Higher Education (Wolverton, Hallman et al. 2015). Sports teams are now also multi-national owned brands in their own right and listed on the public stock exchange. A recent share in the Abu-Dhabi-controlled, English Premier League football team Manchester City was bought by the American private equity firm Silver Lake Partners at a valuation of $4.8-billion US dollars (Jasinski 2020). This investment and importance placed on sports performance on and off the sporting arena, has resulted in the push towards the development of sports science as a multidisciplinary research domain, focused upon improving the understanding and facilitation of sporting excellence.

While sports performance and sports science research are a relatively new field of study, the scientific underpinnings are well established (e.g. motor control, psychology, medicine and biomechanics) (Glazier 2017). In the most recent attempt to gain clarity on the term ‘sports performance’ and develop a framework for its exploration within scientific research, Glazier (2017) proposed a notion towards a ‘Grand Unifying Theory’ of sports performance based around the constraints model originally introduced by Newell, Vanemmerik et al. (1989). The notion proposed that sports performance was the ‘outcome’ of the complex, symbiotic interaction between ‘task’ (sporting activity), ‘organism’ (in this case human), and environment (all manner of external physical, psychological and social factors impacting on the sporting activity and sportsperson). The processes that determine the sports performance outcome were outlined as ‘coordination’ (the internal and external organisation of the body and mind) and ‘control’ (the process of focusing the coordinative function on an action or outcome) and were considered related but conceptually separate. While the attempt at moving towards a Grand Unifying

Theory for sports performance has ultimately been deemed admirable and necessary through the research commentary (Cardinale 2017, Cobley, Sanders et al. 2017, Hackfort 2017, Lopez-Felip and Turvey 2017, Rein, Perl et al. 2017, Seifert, Araujo et al. 2017, Williams and Ward 2017), a common consensus is yet to be reached. Key considerations for the grand unification of sports performance theoretical and applied research from the commentary were that:

a) Differentiating between research centred on predicting the sports performance 'outcome', the processes facilitating and constraining the sports performance 'task' and the management of 'performance indicators and athlete data' that inform both of the above need to be clarified as part of a research framework (Hackfort 2017, Williams and Ward 2017).

b) Human-centred constructs such as sports performance should be approached through a biopsychosocial lens and incorporate multidisciplinary input and design (Cardinale 2017, Cobley, Sanders et al. 2017).

c) Sports performance is considered to be governed by 'complex', 'dynamic' and 'adaptive' systems and thus should be studied accordingly utilising the complexity sciences. Previous learnings from the more established medical and health-based frameworks can aid in this integration (Hackfort 2017, Seifert, Araujo et al. 2017).

d) Given the nature of high-level performance can be atypical to the general population, differ within and between sports, and be influenced by many different growth, maturational and environmental factors, a focus on understanding the 'context' through integrative qualitative and quantitative methods is advocated. Innovations in the areas of wearable technology, remote-athlete monitoring, data analysis and artificial intelligence can aid in the production of longitudinal research specific to the competitive environment and cohort being studied (Cardinale 2017, Rein, Perl et al. 2017).

Future-focused sports performance research needs to consider what aspects of the sports performance construct is being studied and how they interrelate (i.e., outcome vs process/task vs management of performance indicators/data). In relation to the body of work in this thesis, the emphasis is placed on studying and removing barriers to the initial capture and management of athlete data. This in turn helps facilitate informing both the prediction of performance outcomes, readiness/recovery, and their underpinning mechanisms and processes. Sports performance research must look to incorporate multidisciplinary, biopsychosocial approaches, while applying complexity theory and contextual insights in order to best translate findings and practical implications. This can provide a guiding framework for exploring viable remote-athlete monitoring and injury surveillance solutions.

2.3 Investigating Sports Injury

Notwithstanding the health-related benefits of participation in sport, it must also be recognised that there are risks involved such as those from injury (van Mechelen, Hlobil et al. 1992). The burden of injury extends further than that of the individual, having a very real public health impact. European Union statistics estimate the economic costs from sports related injury to be more than 2.4-billion euros when the number of hospital treatment days are accounted for (Kisser and Bauer 2011). The forecast is similar in other countries such as Australia, where hospital admittances between 2002-2010 from sports injuries are estimated to have cost the state of Victoria alone $2-billion Australian dollars annually (Finch, Wong Shee et al. 2014). Specifically in the context of rugby union, where the injury risk is considered high in comparison to other sports (Williams, Trewartha et al. 2013), the ‘cost’ of injuries can be personally and financially far-ranging to both the athletes and their teams or sports. For an athlete, the implications can be viewed as both short and long-term, whereby reducing development and career opportunities through lost playing and training time is apparent, as well as longer-term implications, such as an increase in osteoarthritis and joint replacement (Davies, Judge et al. 2017). For a developing youth athlete, an injury at the wrong time could seriously impact their future aspirations within a competitive development system as well as place them at higher risk for sustaining a future injury. From a team’s perspective, there is a clear direct financial cost resulting from salary and medical expenses, but also indirect costs such as those of decreased performance outcomes, fan engagement, sponsorship and merchandising of which, while hard to quantify, make up the vast majority of sports and teams revenue streams (Drawer and Fuller 2002). Similar assertions, albeit related to areas of funding, health and safety and new student registrations could also be considered across both government and fee-paying schools' settings where academy rugby union players spend the majority of their time.

Compared to sports performance research, sports injury research is relatively well-defined given its foundations in epidemiological medicine. To enable an understanding of the scope (breadth) and magnitude (degree) of injuries in a population commensurate with epidemiological studies, a clear and consistent definition of 'what constitutes an injury' and how the injury problem is described needs to be established (Brooks and Fuller 2006). A consistent injury definition standardises reporting and analysis, improving the comparability of injury across time and different subsets of a population. An injury can be defined both theoretically and operationally and these can vary depending on the sport in question, the research objectives and environment (Verhagen and Van Mechelen 2010). Sporting injury can theoretically be defined (van Mechelen, Hlobil et al. 1992) through the most recent International Olympic Committee Consensus Statement as "tissue damage or other derangement of physical function due to participation in sports, resulting from a rapid or repetitive transfer of kinetic energy" It is, however, typical for many sports to formalise their own operational definitions to standardise practice and account for the contextual differences between sports. This is evident by the many consensus statements currently published by sports such as Baseball (Pollack, D'Angelo et al. 2016), American Football (Deubert, Cohen et al. 2017), Athletics (Timpka, Alonso et al. 2014), Tennis (Pluim, Fuller et al. 2009), Basketball (Drakos, Domb et al. 2010), Ice Hockey (McKay, Tufts et al. 2014), Aquatic Sports (Mountjoy, Junge et al. 2016), Association Football (Soccer) (Fuller, Ekstrand et al. 2006) and Rugby (Fuller, Molloy et al. 2007). The sport in question for this thesis, Rugby Union, theoretically defines injury as ''bodily damage caused by a transfer or absence of energy'' (Fuller, Molloy et al. 2007). This definition is operationally defined using the following parameters.

'Any physical complaint, which was caused by a transfer of energy that exceeded the body's ability to maintain its structural and/or functional integrity, that was sustained by a player during a rugby match or rugby training, irrespective of the need for medical attention or time-loss from rugby activities. An injury that results in a player receiving medical attention is referred to as a 'medical-attention' injury and an injury that results in a player being unable to take a full part in future rugby training or match play as a 'time-loss' injury'. NB: It is anticipated most studies will record time-loss injuries.

A key concern for this thesis is the establishment and maintenance of valid and reliable methodologies that can scale across remote-athlete settings where trained practitioners and appropriate tools are limited. This concern was highlighted in a recent review into injury surveillance systems across sport, whereby a distinct lack of remote-athlete based injury surveillance systems were found to be currently operating (one out of fifteen) (Ekegren, Gabbe et al. 2016). The review concluded that while injury consensus statements and definitions such as those found in rugby union are useful initial first steps, they currently fail to acknowledge the challenges faced by remote-athlete settings across community, amateur and youth development settings synonymous with academy rugby union. Further to this, even across elite/professional sport, few systems report consistent and ongoing data, provide measures of data quality (i.e., data completeness and validity) and thus risk producing erroneous results. Research into the successful design and implementation of athlete monitoring and injury surveillance practices in remote-athlete settings need to consider the applicable injury definition, the sports-specific contextual barriers to implementation and the establishment of context-driven data quality standards.

2.4 Athlete Monitoring and Injury Prevention Models

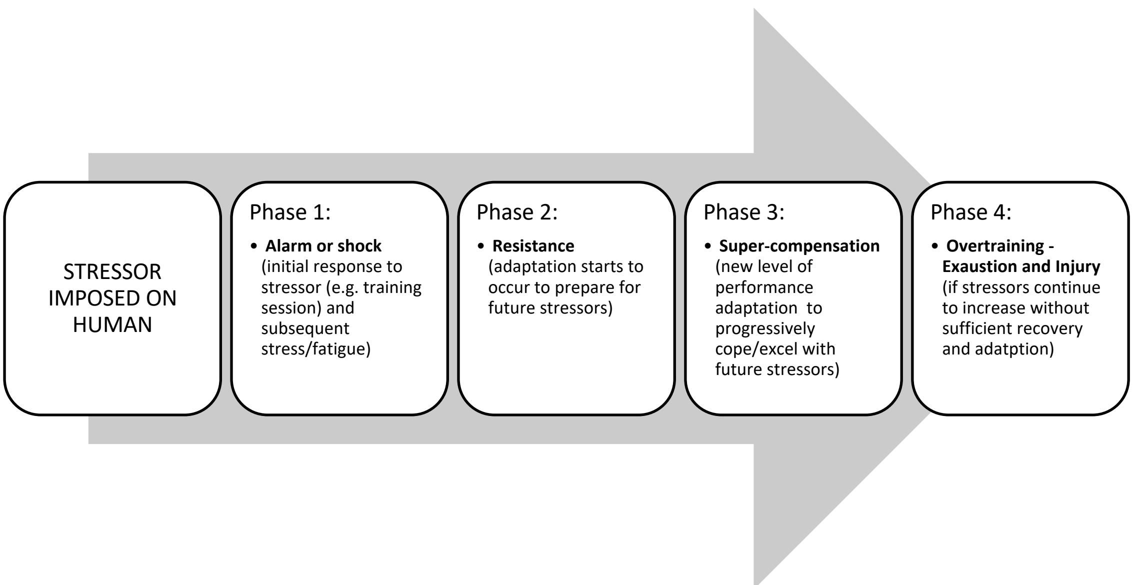
Athlete monitoring and injury surveillance data supports informed decision-making to improve performance and reduce injury in sport (van Mechelen, Hlobil et al. 1992, Finch 2006). Athlete monitoring refers to the ongoing use of athlete biopsychosocial data to maximise the positive and minimise the negative effects of the sporting environment (Gabbett, Nassis et al. 2017). Injury surveillance captures the major negative effect of the sporting environment (injury) and refers to the ongoing, systematic collection and reporting of injury data (Shaw, Orchard et al. 2017). This helps practitioners and researchers to describe the impact, or risk associated with a particular setting or cohort (Kipsaina, Ozanne-Smith et al. 2015). Together, athlete monitoring and injury surveillance allow for the development of effective training prescription and risk management strategies. Utilising learnings from the previous sections on performance and injury, this review now looks to outline current models and theories that conceptualise the type of data to be collected, and the development and implementation considerations athlete monitoring and injury surveillance systems can be built upon.

2.4.1 General Adaption Syndrome Model

In conceptualising the athlete monitoring and injury surveillance process, an understanding of the theory behind how humans respond and adapt to stimuli and their environment is necessary. A representation of the process of positive (performance improvement) or negative (injury) adaptation is illustrated in the General Adaption Syndrome (GAS) model (Selye 1950)

Figure 1. This model details how the application of ‘stressors’ (physical and non-physical inputs that influence homeostasis) prompts an initial fatigue or stress (Phase 1), resulting in a temporary decrement in performance along with muscle stiffness and soreness for a number of days dependant on the magnitude of the stressors. Phases 2 and 3 show that the body will endeavour to return to homeostasis (resistance), and in the presence of appropriate recovery a new level of adaption occurs to cope with that level of stressor in the future (super-compensation). If however there is not sufficient recovery or the stressors continue to increase at an unsustainable rate, overtraining and eventually injury ensue. While the precise physiological mechanisms underlying the progression towards overtraining and injury is not entirely clear, there is a consensus that progression is associated with subjective signs of physical fatigue, and particular stress markers similar to those identified for approaching clinical depression (Saw, Main et al. 2016). This therefore suggests there is some form of interrelated relationship between that of stressors, the stress-response, markers of fatigue, performance adaptions and injury.

Figure 1: General Adaptation Syndrome Model proposed by Selye (1950)



2.4.2 Principles of Sports Training

Sports 'training' refers to the process component of the sports performance construct and involves methodically applying stressors to the athlete with the goal of improving their ability to perform higher levels of sports specific activity, resulting in improved performance (Soligard, Schwellnus et al. 2016). For the successful prescription of training to be achieved, managing the balance of appropriate stressors and recovery to achieve super-compensation is paramount (Foster 1998). This management involves applying 'overload', the principle used to describe and administer the level of stressor (training session/activity) needed to achieve a disturbance in homeostasis (Baechle, Earle et al. 2008). Once overload has been achieved, an adequate recovery period must ensue in line with the GAS model so that a positive training adaption can occur. Information on training variables such as frequency, intensity, time and type (FITT principle) can therefore aid in evaluating the training stimulus (stressors), the appropriate overload, and ultimately the better management of training balance (Baechle, Earle et al. 2008). Due to the complex demands of team sports such as rugby union, multi-component training programs are needed in order to meet the requirements of the game (Till and Jones 2015). This means that a particular emphasis is placed on having the information needed to inform training prescription. It is therefore important for the appropriate design of training and performance improvement programs in academy rugby union that practitioners have access to the required variables to inform and plan. Developing remote-athlete data capture strategies that can consistently provide information on the frequency, intensity, time and type of activity as well as other stressors (e.g. life hassles) can aid practitioners in the appropriate application of overload to manage the balance of training.

2.4.3 A Dynamic, Recursive Model of Injury Aetiology in Sport

In 1994 Meeuwisse developed the 'multi-factorial model of injury causation' (Meeuwisse 1994) then subsequently updated this in 2007 to the 'dynamic, recursive model of injury aetiology in sport' represented in Figure 2 (Meeuwisse, Tyreman et al. 2007). These models are useful in order to understand the type of data that needs to be captured within athlete monitoring and injury surveillance systems. The aetiology models describe the causal pathway of injury as the interaction between 1) an athlete's individual capabilities and pre-existing physical and physiological state (intrinsic risk factors), 2) the events, situations and environmental surroundings imposed on the athlete as part of competition, training and life (extrinsic risk factors) and 3) a particular inciting event (contact with another player or the ground). Extrinsic and intrinsic risk factors can render an athlete susceptible to injury but require an ‘inciting event’ to cause an injury. Not all inciting events however result in injury. This can be seen throughout any match or training session where multiple potentially injurious inciting events occur without injury. This was the reason for the updated model in 2007, whereby multiple event lines can be seen going towards ‘No Injury’, suggesting a more cyclic process of multiple inciting events that may or may not result in injury. Another important addition to the revised model was the idea that participation itself could alter the intrinsic risk-factors by way of adaptation and subsequent supercompensation to the imposed extrinsic risk-factors and inciting events. What the model does not clearly illustrate though is the process behind this and how ‘non-physical’ risk factors relating to the cognitive stress-response cycle could also interact to impact injury risk. The addition of markers of cognitive appraisal and life demands and monitoring the process and consequences of those risk-factors through continuous cycles of participation, regardless of injury outcome is where the notion of athlete monitoring has become useful in developing a level of understanding beyond the initial physical and musculoskeletal risk-factors.

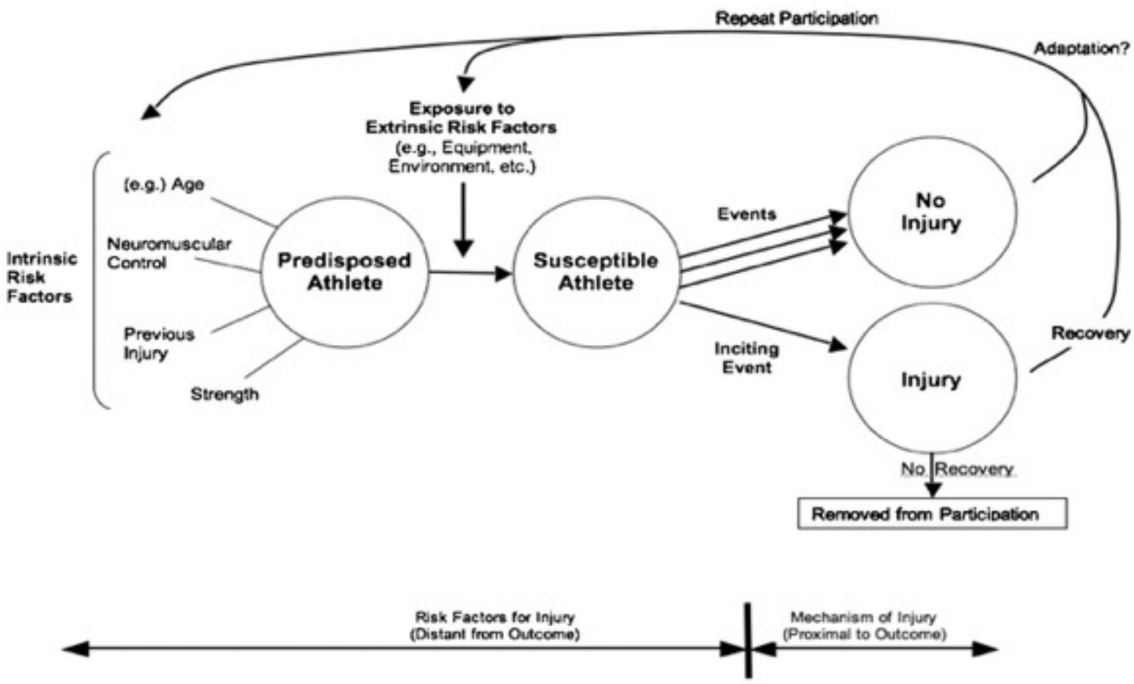


Figure 2: A Dynamic, Recursive Model of Injury Aetiology in Sport developed by (Meeuwisse, Tyreman et al. 2007)

2.4.4 A Workload Model of Physical Performance and Injury in Sport

A recent physical performance and injury aetiology model iteration, proposed by Windt and Gabbett (2017), details how specifically physical training and competition can influence fitness and injury (Figure 3). According to the 'Cumulative Load Theory', repetitive and prolonged exposure to physical loads (without adequate recovery) may weaken the stress-tolerating capacity of muscle and bone structures to a degree that normal physical loads become injurious (Kumar 2001). The principles of this model are based on the seminal work of Calvert, Banister et al. (1976) whose systems model of physical performance considered both the positive (fitness) and negative (fatigue) effects of training. Combining this Fitness and Fatigue Systems Model, with that of the Dynamic, Recursive Model of Injury Aetiology, Wind and Gabbett illustrated how the application of 'workload' in conjunction with other extrinsic and intrinsic risk factors and subsequent inciting events could influence performance and injury-risk. The authors extended previous models by proposing 'workloads' (combined physical demands of the sport e.g. running, jumping, tackling, throwing) as contributing to the dynamic injury risk of an athlete through three mechanisms; 1) they constitute an exposure and thus likely invite further inciting events and other extrinsic risk factors, 2) they induce fatigue thus in the presence of particular internal risk factors and inadequate recovery increase injury risk and 3) they induce fitness a positive adaptation and thus alter internal risk factors positively. It is this interplay that has been described as the workload-injury prevention paradox (Gabbett and Whiteley 2017). The paradox is that workloads can present as both a preventative and risk inducing factor. This has been documented in youth rugby players in Australia whereby players experiencing higher volumes of activity exposure showed a better ability to cope with more congested training and playing schedules, however players also presented with symptoms stress and fatigue that were considered precursors to overtraining and potential injury and illness (Hartwig, Naughton et al. 2009). While the model presents a clearer depiction of how global physical stressors can impact injury and performance the limitations are again similar to that of the Dynamic, Recursive Model. It does not account for stressors outside of physical competition and training (e.g. life stressors and other psychological stressors) and how workload may influence different injury types (e.g. acute vs chronic, contact vs non-contact). Combining physical workload variables with that of psychosocial factors and injury data may provide a more complete understanding and array of variables in which academy rugby union stakeholders can make informed decisions around athlete monitoring and injury surveillance data capture.

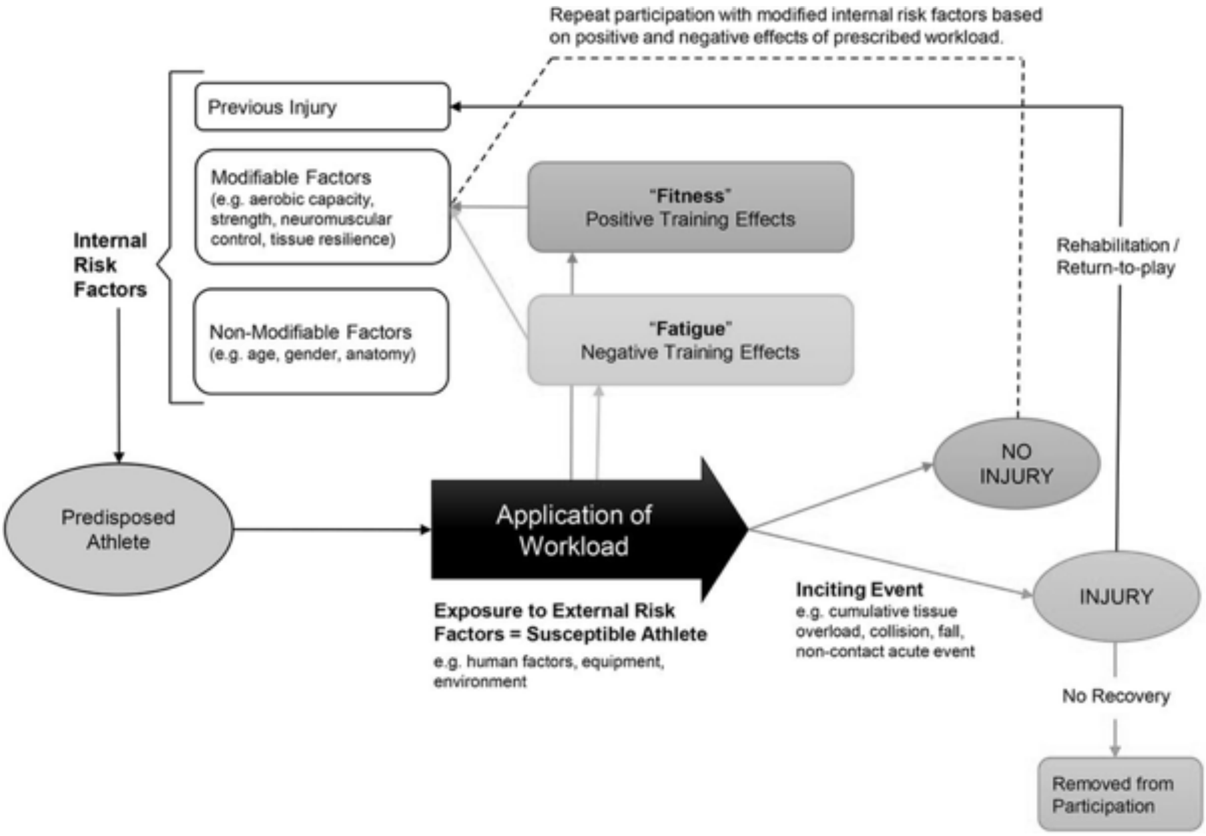


Figure 3: Workload Injury Aetiology in Sport Model proposed by (Windt and Gabbett 2017)

2.4.5 Psychosocial Model of Sports Injury

To compliment and extend the understanding of previous physical and workload-based models of injury and performance, the addition of non-physical and psychosocial aspects of the stress has been noted. In contemporary settings, the term 'stress' is viewed as an 'ongoing process whereby an individual is constantly making appraisals of the situations they find themselves in, demands being placed on them and endeavouring to cope' (Fletcher, Hanton et al. 2012). According to Andersen and Williams (1988) in their original proposition of the interactions between stress and injury, when athletes experience stressful situations such as demanding competition and training workloads or negative life-events, interactions between their 1) personality characteristics, 2) history of stressors (e.g. daily hassles, life stress and previous injury or illness), and 3) coping resources (e.g. social support, stress management, mental skills, medication), impacts their stress-response. This can be depicted in the simplified and updated model in Figure 4. The authors hypothesise that athletes with poor psychosocial profiles will appraise situations as more stressful, and exhibit greater physiological activation (e.g. heart rate, muscular tension) and attentional disruptions compared to those that exhibit the opposite profile. The severity of the stress-response reaction from an individual is considered the mechanism of injury. A similar proposition could be afforded to psychosocial influences on sports performance outcomes whereby managing the stress-response through monitoring interventions and progressive overload can yield both injury-risk reduction and gradual performance improvements.

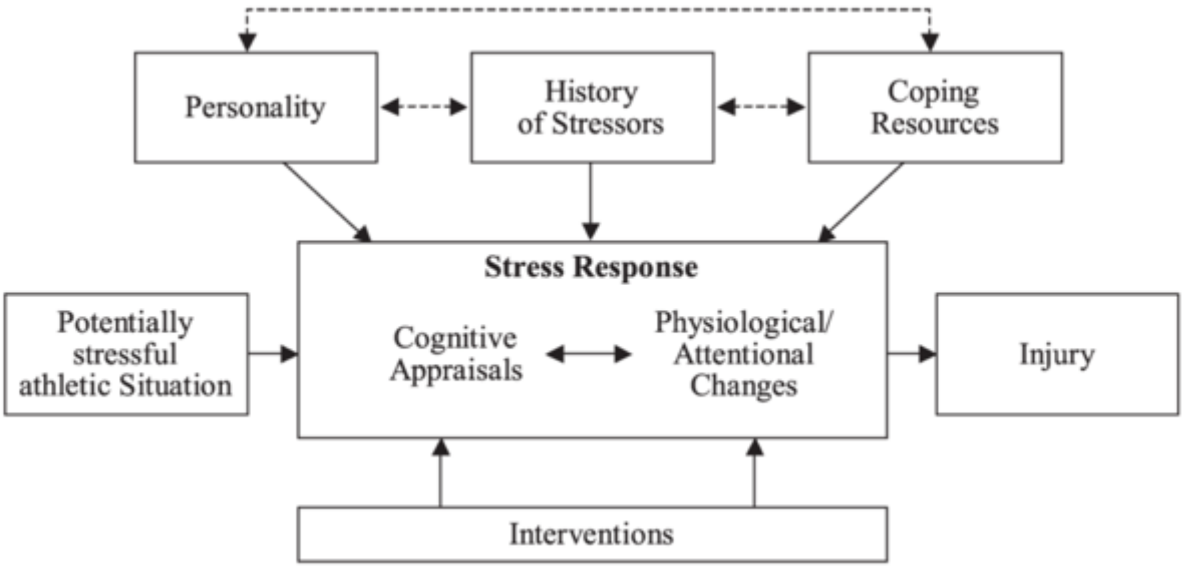


Figure 4: A Model of Stress and Athletic Injury proposed by Andersen and Williams (1988) with updates by Williams and Andersen (1998)

While more encompassing than the Workload Aetiology Model given the addition of non-physical stressors (potentially stressful athletic situation) and previous workload (history of stressors), the Psychosocial Model does still focus on the 'psychosocial' aspect rather than embrace a more inclusive biopsychosocial approach as has been recommended throughout the previous sports performance and injury section (Seifert, Araujo et al. 2017). A biopsychosocial view advocates contextualising both physical and non-physical aspects of sports performance and injury with biological (body), psychological (mind and behaviour) and sociocultural (interactions with others and institutions) factors (Wiese-Bjornstal 2010). The presence of a biopsychosocial viewpoint opens athlete monitoring and surveillance strategies to considering school/academic, family and relationship stressors and changes in related behaviour which is of particular relevance to academy rugby union athletes. While there are biopsychosocial models of injury present in the literature (Wiese-Bjornstal 2010, Appaneal and Perna 2014) they do not provide the visual illustration of the previous models so therefore are better suited as guiding principles in which future-focused athlete monitoring and injury surveillance practices can evolve. Another consideration of the psychosocial models is the practical application of some of the traditional research and their methodologies in which the models are built upon. In-depth questionnaires and interviews to unpick such aspects as personality and the constantly changing appraisals associated with stress would need to be considered, especially in remote-athlete academy rugby settings where access and time resources are low. However, the potential to combine aspects of the psychosocial and workload models, and then adapt them guided by practical, biopsychosocial principles is worth considering for future-focused athlete monitoring and injury surveillance research.

2.4.6 The Athlete Monitoring Cycle

The Athlete Monitoring Cycle proposed by Gabbett, Nassis et al. (2017) is a recent framework in which a biopsychosocial, but workload-focused approach to the athlete monitoring process is described in Figure 5. The authors detail an approach whereby an athlete is 1) exposed to a training stimulus, referred to as 'external workload', 2) their response to this stimulus is then monitored (internal workload), 3) followed by an assessment as to whether they are perceived to be tolerating the load (perceptual wellbeing), and 4) whether they are ready to complete further training or competition (readiness). The framework follows the concepts of the GAS model but applies a practical focus on tracking and actioning the variables to monitor and plan appropriate physical overload, while managing predefined markers of biopsychosocial stress and fatigue. This can be seen within the boxes A, B and C whereby each section is used to inform the previous sections decision-making. For example, the authors detail the first consideration is the relationship between the external work performed by the athlete, with that of their internal response. If the athlete performs higher levels of work than planned, and their internal response is also higher than usually monitored (BOX A), it may be necessary to reconsider training design as further training in this manner may lead to maladaptive (overtraining or injury) outcomes. Combining this relationship with that of measures of perceptual wellbeing can also help indicate whether aspects other than the training program are influencing the internal: external relationship e.g. life stressors, poor nutrition or sleeping habits. Finally, information relating to the athlete's baseline or required physical and mental characteristics may be assessed to determine whether both a desired training outcome has occurred, and/or whether further recovery or specific support (soft-tissue therapy, nutrition, sleep, psychology) is needed before additional training or competition is warranted. The Athlete Monitoring Cycle outlines a basic decision-making framework for athlete monitoring. For remote-athletes, such as those in the academies, capturing all the different forms of external workloads, together with the time and access to practitioners that can help interpret this information is a challenge. It is also suggested by the authors that successful approaches to athlete monitoring should consider a comprehensive education program that ideally supports the athlete themselves, and their key stakeholders (coaches, parents, schools). It is therefore important to consider designing tools, processes and educational support that specifically cater to your target population and aims. These strategies should aid in both the capture and active participation of athlete monitoring practices by all key athlete development stakeholders if both successful implementation and interpretation are to occur.

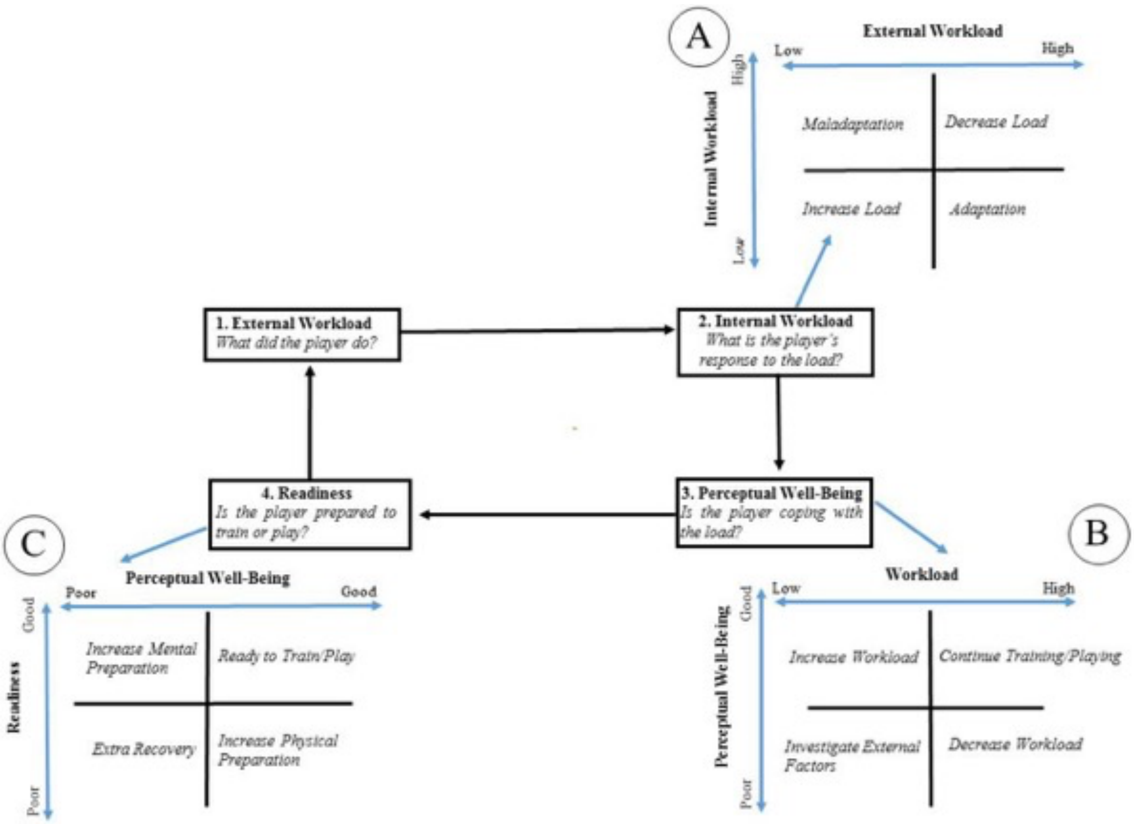


Figure 5: The Athlete Monitoring Cycle proposed by Gabbett, Nassis et al. (2017)

2.4.7 The Sequence of Prevention

The Sequence of Prevention is a model developed by van Mechelen, Hlobil et al. (1992) that illustrates the concepts and steps to consider when attempting to prevent injuries in sporting populations. Based upon the public health preventative research model at the time (Robertson 1992), the Sequence of Prevention is characterised by four stages (Figure 6). Stage one outlines that the extent of the injury problem must first be described utilising consistent definitions and outcome measures of incidence and severity. This not only explains the injury problem but details how it was determined. Stage two utilises the information from stage one and then establishes the underlying factors and mechanisms that contribute to those injuries occurring. This can therefore inform stage three, whereby specifically designed preventative measures are introduced, then evaluated in terms of effectiveness in stage four by repeating the first stage to ascertain any meaningful changes. It is important to note that the difference between ‘effectiveness’ and ‘efficacy’ is that efficacy relates to clinical randomised controlled trials and ‘effectiveness’ whether the efficacy can be seen in practice (Bolling, van Mechelen et al. 2018). This suggests contextual trials need to be undertaken within the model but there is little insight into how this can be achieved. The Sequence of Prevention model is arguably the first and most well-known injury prevention model in sport, with most models thereafter adapting its fundamental ideas. A well-known limitation, however, is its inability to incorporate, and explain the behavioural factors experienced as part of the implementation and acceptance of preventative strategies. This is important when considering the overall effectiveness of athlete monitoring and injury surveillance strategies and systems, and therefore utilising other guiding models and frameworks are necessary.

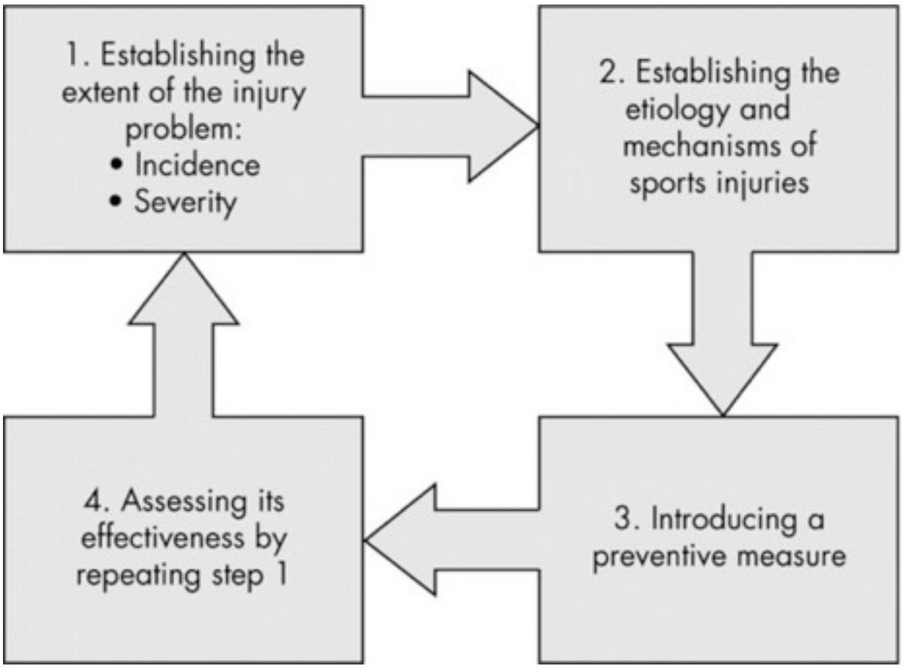


Figure 6: The Sequence of Prevention Model developed by van Mechelen, Hlobil et al. (1992)

2.4.8 Translating Research into Injury Prevention Practice (TRIPP) Framework

The TRIPP framework (Figure 7) proposed by Finch (2006), expands upon the Sequence of Prevention to address the limitations surrounding evaluating the effectiveness of prevention strategies. The framework accounts for preventative strategy efficacy, but also identifies the contextual understanding of the environment in which the interventions will be placed as important considerations. This can be seen in stage 4, whereby clarification is made between testing the effectiveness of preventative strategies in ideal/scientific conditions and that of real-world environments e.g. if the strategy is ineffective in ideal settings there is no need to test in real world, whilst if it is effective in ideal conditions but ineffective in real world there are probably contextual and behavioural factors to consider. This therefore allows practitioners to determine factors that may facilitate, or limit the uptake and adherence of, any proposed preventative strategies (stages 5 and 6).

Model stage	TRIPP	van Mechelen et al 4 stage approach
1	Injury surveillance	Establish extent of the problem
2	Establish aetiology and mechanisms of injury	Establish aetiology and mechanisms of injury
3	Develop preventive measures	Introduce preventive measures
4	"Ideal conditions"/scientific evaluation	Assess their effectiveness by repeating stage 1
5	Describe intervention context to inform implementation strategies	
6	Evaluate effectiveness of preventive measures in implementation context	

Figure 7: Translating Research into Injury Prevention Practice (TRIPP) Model developed by Finch (2006)

The TRIPP framework also introduces a particular change of focus specific to this review within stage one. It suggests that the previous approach of repeatedly circling back to stage one and performing cross-sectional epidemiological research (i.e. one team in one sport in one country/region at one point in time), limits the evaluation of the injury problem and the impact of preventative measures (Chalmers 2002). Therefore, the TRIPP framework proposes moving towards an 'injury surveillance' approach in stage one, whereby epidemiological methods are set up to run continually as part of general practice. This reduces the gaps in data collection and limits some of the aforementioned issues presented by cross-sectional injury epidemiological studies, moving more towards an ongoing, longitudinal prospective cohort design. This is particularly relevant to the current body of research surrounding the activity exposure and injury rates of academy rugby union players. Current activity exposure research, while methodologically sound, has limited application and validity across the academy landscape as research is restricted to a single academy, with the same players, across a relatively short period of time (Phibbs, Jones et al. 2017, Phibbs, Jones et al. 2018, Phibbs, Jones et al. 2018). The most recent injury studies on the academy rugby union population are more than 10-years old (Palmer-Green, Stokes et al. 2013, Palmer-Green, Stokes et al. 2015) therefore, it is unknown whether these injury patterns are still applicable today due to the advances in preparation, technical and tactical approaches, research and rule changes seen in the sport (Till, Weakley et al. 2020). Both limitations represent areas that a surveillance approach could potentially eliminate given it is designed to run continuously and as part of general practice.

2.4.9 A Risk Management Framework for Sports Related Injuries

Proposed by Fuller and Drawer (2004), this framework incorporates ‘The Sequence of Prevention’ and ‘TRIPP’ propositions but applies an organisational risk management approach (Figure 8). Risk management was explained as ‘the overall process of assessing and controlling risks within an organisational setting’. A ‘risk factor’ referred to a ‘condition, object or situation that may be a potential source of harm to people’ and, ‘risk’ itself, ‘the probability of the risk-factor having an impact on these people’ (Fuller and Drawer 2004). The framework begins with the identification of risk factors from epidemiological studies (surveillance), but in contrast to the Sequence of Prevention and TRIPP Framework, positions some of the ‘intervention context’ investigations before the development of preventative measures. This is of particular relevance to this review given that capturing the necessary stage one athlete epidemiological data from regional academy and other remote-athlete populations already presents challenges. Understanding the perceptions of current information compared to empirical data, and risk compared to reward in these populations before any data is collected can be considered a limitation of the Sequence of Prevention and TRIPP Framework and one that the Risk Management Framework provides some insight into addressing. Moves towards estimating and evaluating the acceptability of current information, practices and their outcomes as perceived by key stakeholders could inform the development and implementation of strategies for athlete monitoring and injury surveillance. While the Sequence of Prevention and TRIPP Framework address the key steps to delivering injury reduction outcomes, the Risk Management Framework could be used to position, describe and translate athlete monitoring and injury surveillance data and the methods currently used to capture it more effectively.

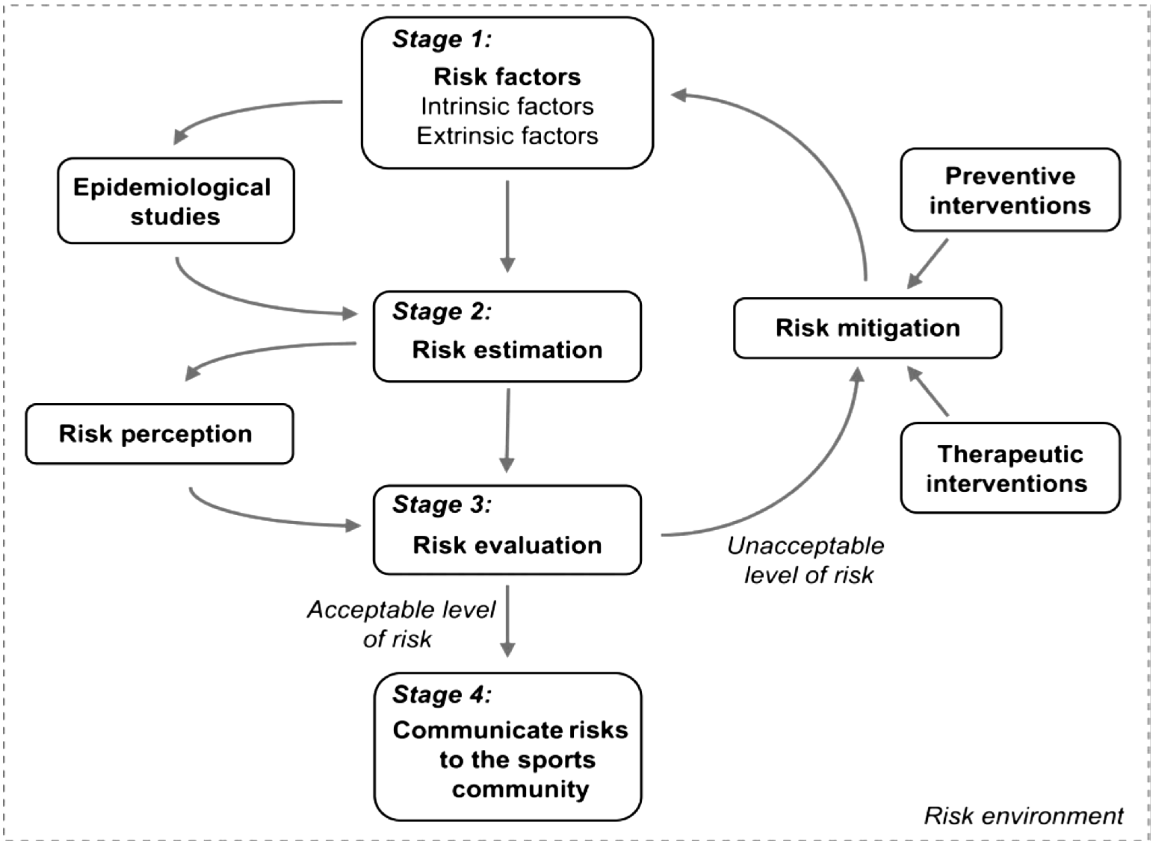


Figure 8: A Risk Management Framework for Sports (Fuller and Drawer 2004)

2.4.10 Complex Adaptive Systems Theory

The traditional models of sports performance and injury are seen to view their outcomes and the mechanisms underpinning them using a ‘reductionist’ approach. They endeavour to simplify systems into parts, that interact in an additive way, are then summed, and if a threshold (overload) or inciting event breaches capacity, a performance or injury outcome will occur. Complex Adaptive Systems (CAS) Theory takes an ecologically focused, multi-faceted, self-organising and non-linear approach to sports performance and injury management (Braithwaite, Churruca et al. 2018). The central difference to that of more linear theory’s is that while risk factors, performance indicators and inciting events (all classed as determinants) are important, the relationships between these (interaction-profiles) and monitoring how they constantly change have a greater bearing on understanding the outcome (Braithwaite, Churruca et al. 2018). For example, in a narrative review by Bittencourt, Meeuwisse et al. (2016) the authors illustrate that sports injury is influenced through a ‘web of determinants’ rather than a recursive separation of sequential risk factors followed by inciting events. Figure 9 shows despite the outcome in both cases being an ACL injury, the Baseball (A) and the Ballet (B) web of determinants are different with certain units within the web having a larger impact depending on the context. Proponents of complexity theory therefore suggest studying the ‘regularities’ in athletes and sports ‘interaction-profiles’ can lead to a more comprehensive understanding of the causal pathway and deterministic processes of sport. This moves the focus from isolated determinants, to injury and performance pattern recognition, allowing for the incorporation of multiple factors (intrinsic, extrinsic, inciting events) on multiple levels (biopsychosocial) simultaneously interacting to help explain how best to address positive change in these systems.

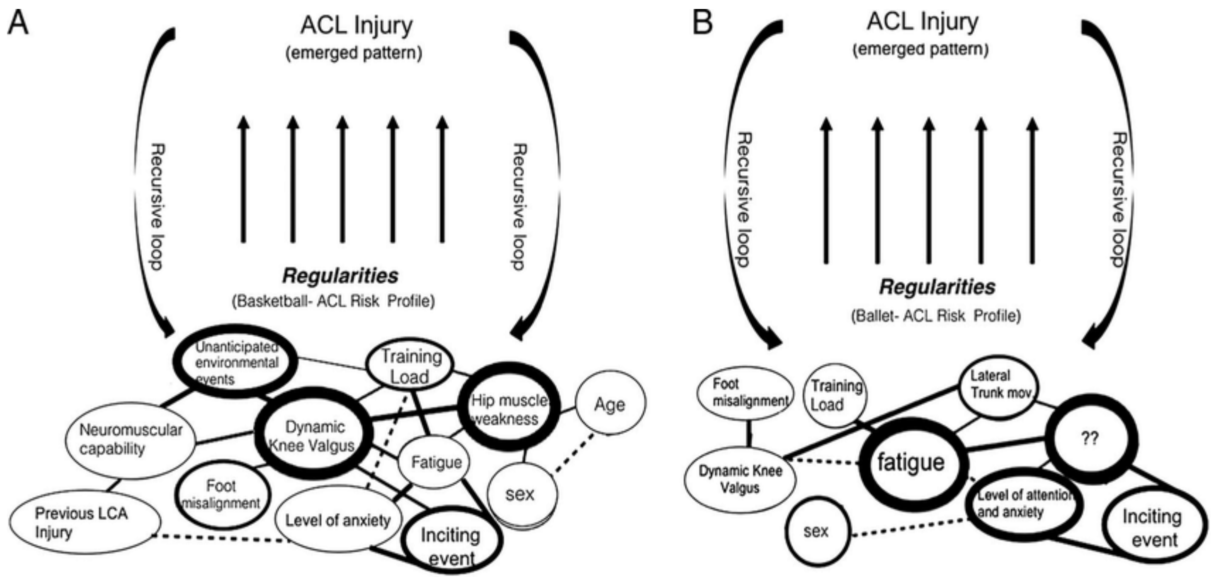


Figure 9: A depiction of the 'web of determinants' within a complex system for ACL injury-risk where (A) refers to a Baseball player and (B) a Ballet Dancer by Bittencourt, Meeuwisse et al. (2016)

On the surface, it seems a logical next step to embrace complexity in sports performance and injury management given the summary by Glazier (2017), and the ambition of Meeuwisse, Tyreman et al. (2007) to move to a context-driven, dynamic and recursive approach. It has however been suggested the quantity of quality data, and the statistical methods currently employed, may not support a model with both the precision and contextual realism to adequately utilise complexity theory and its web of determinants (Bittencourt, Meeuwisse et al. 2016, Hulme, Salmon et al. 2017). While the combination of both artificial intelligence (AI) methods (Claudino, Capanema et al. 2019), and applying systems ergonomics frameworks (Hulme, Thompson et al. 2019) has recently been proposed as an avenue to addressing these issues, it is beyond the scope of this review and the current literature base to provide evidence-based solutions at present. What is evidently apparent however is that there is a need for sports performance and injury research to consider approaching research questions from an ecological, whole of sport perspective and focus on the interactions between factors spanning its multiple levels. In its current state, complexity theory provides a complimentary approach that can help frame thinking towards both the breadth, and depth of athlete monitoring and injury surveillance data capture and the context in which it is performed. Specifically, for the remote-athlete academy rugby system, this type of approach could aid in both the understanding and innovation required to reduce the barriers to data capture. This could relate to selecting performance and injury variables, models and strategies that have the ability to simultaneously explain both the context and deterministic process, together with top-down (policy, governance, use metrics), middle-out (key operational decision-makers and transfer of information) and bottom up (athletes views of quality and use) evaluation and implementation.

2.4.11 Summary of Foundations of Athlete Monitoring and Injury Prevention:

- Central to existing models of athlete monitoring and injury prevention are explanations of the stress-response cycle and the causal pathway of injury. The explanations illustrate a stressor-response-injury continuum that can provide insight into the basic structure and function of athlete monitoring and injury surveillance systems design.
- It is suggested data relating to 1) the contextual environment (multi-level ecological data), 2) biopsychosocial descriptors of training and competition stress-response, and 3) injury epidemiology, is needed to represent the multi-faceted nature of sport.
- A key finding from the review refers to the placement of important contextual information being collected towards the end of the models presented. This could be limiting the ability to capture the quantity and quality of data in the first place through inappropriate design and evaluation procedures.
- In order to reflect the growing acceptance that sports performance and injury are in fact emergent outcomes from complex systems, research and development should look to embrace

strategies that include whole of sport approaches that focus on pattern-recognition profiling, rather than isolating variables, and involve top down, middle-out, and bottom-up implementation and evaluation.

Considering the aforementioned findings, this review will now focus on 1) identifying biopsychosocial approaches to remotely capture regional academy rugby player stress-response and injury data, and 2) the development and evaluation research strategies that can provide important multi-level contextual implementation information.

2.5 Biopsychosocial Approaches to Athlete Monitoring and Injury Surveillance

The previous section highlighted that, while linear, one-dimensional approaches can provide detailed and translatable accounts of the individual biological, psychological and social components of athlete monitoring and injury surveillance strategies, they may not be entirely representative of the multi-directional and dimensional interactions these strategies should cover. Embracing a contextualised and interrelated physical and non-physical view of the bio (body), psycho (mind and behaviour) and social (interactions with others and institutions) components can help provide researchers and practitioners with a more comprehensive understanding. The following section of this thesis aims to establish key definitions and terms related to the capture of biopsychosocial stressors, responses and injury, then overview the current methods used to quantify athlete monitoring and injury surveillance and finally evaluate viable methods to capturing remote-athlete data.

2.5.1 Terminology and Definitions

Understanding the encompassing terms and key definitions used in the athlete monitoring and injury surveillance literature is important to establishing a framework in which useful and viable remote-athlete data capture methods can be identified. In 2015 the International Olympic Committee convened an expert group to review scientific evidence and establish consensus on the interaction between the athletic stress-response cycle and injury-risk (Soligard, Schwellnus et al. 2016). The review included studies from recreational to elite populations where injury was either self-reported or clinically diagnosed in relation to sporting competition, training, psychological or travel stressors and their biopsychosocial response mechanisms. The term ‘load’ was used to encompass the measurement of these stressors and was defined as; *‘The sport and non-sport burden (single or multiple physiological, psychological or mechanical stressors) as a stimulus that is applied to a human biological system (including subcellular elements, a single cell, tissues, one or multiple organ systems, or the individual)’.* (Soligard, Schwellnus et al. 2016). More recent systematic reviews have established a growing evidence base for the load-injury relationship but have suggested that inconsistent and contradictory definitions of load have made it difficult to conceptualise and amalgamate this area of research into a clear relationship (Drew and Finch 2016, Jones, Griffiths et al. 2017, Eckard, Padua et al. 2018). The central inconsistency stems from whether load refers to the external stressors applied to an athlete as part of the sporting environment, or the measurement of the athlete's response to that load, or whether it is both (Impellizzeri, Marcora et al. 2019). The explanation from Soligard et al. (2016) that both 'external loads' (stressors imposed on the athlete) and 'internal loads' (the athlete's psychophysiological response to external loads) are measured to quantify 'total load' is somewhat contradictory. Considering load, according to their definition, is an 'applied' stressor, it can therefore only be external, and quantified as such. Mixing the load (external stressor) with the response has also been an issue identified in the sports psychology literature (Fletcher, Hanton et al. 2012). This has particular implications towards the interpretation of data, whereby the source of load preceding the response may be hard to discern or worse, overlooked completely if measures are mixed. In addressing this contradiction and applying the definition of load to a rugby union context, Quarrie et al. (2017) stipulates in a recent consensus statement that in order to reduce confusion, load relates to the measurement of external stressors imposed on the athlete, with the response to that load being a separate, but interrelated construct along the load-response-injury aetiological continuum and dynamic, recursive cycle. The application of load as an encompassing term to capture the biopsychosocial stressors imposed on academy rugby union athletes in this thesis is therefore defined using the consensus statement for load in rugby union.

'The total stressors and demands <u>applied</u> to the players, comprising both rugby-related and non-rugby-related inputs, of which the components can be characterised according to their frequency, intensity, duration and type, and the individual's response to the load applied, appraised through either objective or subjective methods' (Quarrie, Raftery et al. 2017).

2.5.2 Summary of Terminology and Definitions:

- Load encompasses the rugby and non-rugby-related stressors or situations an athlete may find themselves exposed to as part of rugby union and represents an approach to capturing the first stage of data for an athlete monitoring and injury surveillance system.
- The second stage relates to capturing, and appraising the individual athlete's response, of which can be quantified using both objective and subjective methods.
- The third and final stage relates to the capture of outcomes (injuries) through both the surveillance means (discussed in the following section), and the reporting of specific

performance indicators (e.g. points scored, tackles completed, work-rate) and outcomes (e.g. wins and losses, development benchmarks).

STEP	TERMINOLOGY		DEFINITION
1	ATHLETE 'LOAD' MONITORING		STRESSORS & DEMANDS IMPOSED ON ATHLETES
2	ATHLETE 'RESPONSE' MONITORING		ATHLETE STRESS-RESPONSE
3	PERFORMANCE OUTCOMES/ INDICATORS	INJURY SURVEILLANCE	POSITIVE AND NEGATIVE EFFECTS OF SPORTING ENVIRONMENT

Figure 10: Illustration of the applied Athlete Monitoring and Injury Surveillance Definitions and Terminology for this Thesis

In examining the literature and for the purposes of this thesis, the theoretical framework for building a biopsychosocial approach to athlete monitoring and injury surveillance will use terminology relating to the load-response-injury interaction.

2.6 Quantifying Load-Response-Injury Interactions

2.6.1 Sources of Athlete Load

The load imposed on an athlete can be both sport and non-sport related and come from both physical and non-physical sources (Soligard, Schwellnus et al. 2016, Quarrie, Raftery et al. 2017). To provide a greater level of understanding into the variety of loads experienced by athletes, Mellalieu, Neil et al. (2009) interviewed 6 elite and 6 non-elite athletes between the ages of 19 and 54-years. The authors completed in-depth interviews and identified three categories of load sources 1) organisational, 2) competition and training, and 3) personal. Synthesising the authors extensive framework of sources, together with expert opinion, Quarrie, Raftery et al. (2017) applied the findings more specifically to what would be considered common sources of load for professional rugby union players (Table 1). While both provide examples of the core sources of load for athletes and specifically rugby union, these examples are not specific to academy rugby union players who are predominantly under-18 years of age.

Table 1: Sources of Load from Professional Rugby Union Players proposed by Quarrie, Raftery et al. (2017)

Physical Loads	Preparation for Matches	Nutrition	Interpersonal Relationships	Personal Development	Other Demands/ Loads
Matches	Travel • Jet lag • Travel Fatigue	Eating for Body Composition	Family and Friends	Career Planning for Life After Rugby	Sponsorship and Media Commitments
Training • Team Practice • Individual Gym-based training • Rugby Conditioning • Recovery • Fitness Testing	Performance Analysis • Learning team tactics/ play patterns • Match reviews and previews	Timing and Content of Meals for Performance	Teammates and Staff	Study and Other Employment	Community Promotions • Coaching sessions at schools/ clubs
Injury and Illness Management/ Rehabilitation		Alcohol/ Drug use	Agents and Managers		Drug Testing
		Supplement use	Fans and Media		Socialising

From the limited studies investigating the physical loads on youth rugby athletes, similar sources of competition, training and recovery from their chosen sport are noted (Hartwig, Naughton et al. 2009, Gabbett, Whyte et al. 2014, Murray 2017, Phibbs 2017, Britton, Kavanagh et al. 2019). There are, however, unique sources of load to that of adolescent, youth athletes. The experiences of youth athletes within an Australian athlete development pathway show that these athletes struggle with how to specifically navigate this environment as it is perceived different to their peers and that of senior professionals (Elliott, Drummond et al. 2018). In a longitudinal case study approach, Hayward, Knight et al. (2017) interviewed four female swimmers between the ages of 14 and 15, their parents and a coach to investigate the stressors placed on youth athletes. Alongside many similar loads to that listed by both Mellalieu, Neil et al. (2009) and Quarrie, Raftery et al. (2017) they also identified schooling/academia and its associated scheduling and assessment, peer-social and family relationships, casual work and jobs outside of school, growth and maturational stressors. The obvious limitation to these findings is that this was a small cohort from a different sport and gender than male academy rugby union players. Similar assertions from the general adolescent stress literature (Compas, Orosan et al. 1993) and less specifically detailed, male adolescent sporting cohorts (van Rens, Borkoles et al. 2016, Kristiansen 2017, Elliott, Drummond et al. 2018), however, support the findings meaning that parallels could be made given the age and environmental profiles of the athletes are similar. Adolescent gender differences in coping with stressors also seems to show more similarities than differences (Hoar, Crocker et al. 2010) so there is a stronger sense parallels can be made.

Other sources of load to consider within youth athletes are multi-sport and level involvement and the stressors that come with it (Malisoux, Frisch et al. 2013). It has been shown that academy rugby players will compete in several other levels of rugby (international, academy, school, club, county) as well as potentially several other sports, which is different compared to senior professionals whereby their full-time focus is on a single sport (Phibbs, Jones et al. 2017, Phibbs, Jones et al. 2018). Given many academy players are selected as part of the national age-grade squads, investigations into sources of load placed on England international under-18 rugby union players is also relevant. The investigations suggested coach and parent criticism and perceptions of ability to cope with their sporting demands are also sources of load for generally are of academy rugby union players (Ar and Polman 2007). Of further consideration is that sources of load can vary between, and within players from day-to-day, over competitions and across careers, with adolescence being a highly sensitive individual period of development (Rith-Najarian, McLaughlin et al. 2014). Monitoring these loads consistently and longitudinally is therefore warranted to gain perspective and understand how these loads change and evolve over time.

2.6.2 Step 1: Quantifying Athlete Load

To capture the range of both physical and non-physical load's an athlete may be exposed to, a wide variety of methods and measures have been proposed. As part of their consensus statement regarding the management of athlete loads, Bourdon, Cardinale et al. (2017) reviewed common practices and their implementation considerations (Figure 11). Considered 'external measures' given they are quantifying load applied to the athlete, the methods reviewed broadly accounted for categories of load frequency (sessions, days, weeks, months periodisation cycles), intensity (accelerations, speeds, power/neuromuscular/metabolic outputs, weight lifted), time/volume (sets, repetitions, seconds, minutes, hours, event counts), and type/mode (gym, training, competition, recovery, nutrition, negative life events, social and media events). The authors note that a combination of methods should be used and ideally, both individual (session/day) and cumulative (weekly/monthly) calculations, utilising a range of descriptive categories (frequency, intensity, volume/time, type/mode). This is so practitioners and researchers can gain as much context to the measures as possible in order to provide a balanced perspective towards training prescription and outcome effects. A simple example could be recording that athlete A has completed two (frequency) strength training (type) sessions this week (frequency) and lifted 50-kilograms (intensity) for three sets of five repetitions (volume). This example could be tracked each session/day individually, and cumulatively over weeks and months to ascertain changes in any of these load variables. With the further development of sports technologies, GPS and accelerometer data are now being used to provide greater detail to the previous example by providing measures relating to distance, accelerations and velocities. It is however cautioned by the authors that each method and measure of load should consider the benefits and limitations. **Error! Reference source not found.** highlights some of the key implementation considerations, whereby the time, cost, equipment, reliability, validity, ease of use and standard of competition and staff are all factors in the viability of these methods. Careful deliberation is therefore required when choosing a selection of load capture methods and variables in order to collect the right balance of quality, quantity and specificity for athlete monitoring and injury surveillance needs.

Method	Cost	Hardware needed	Software needed	Ease of use	Valid	Reliable	Used to interpret	Used to prescribe	Variables
External Measures									
Time	L	Y	Y/N	H	H	H	Y	Y	Units of time (s, min, h, d, wk, y)
Training frequency	L	N	N	H	H	H	Y	Y	Session count
Distance/mileage	L	Y/N	Y/N	H	H	H	Y	Y	Units of distance (m, km)
Movement repetition counts	L	Y/N	Y/N	M–H	H	M–H	Y	Y	Activity counts (eg, steps, jumps, throws)
Training mode	L	Y/N	N	H	H	H	Y	Y	Weight training, run, cycle, swim, row, etc
Power output	M–H	Y	Y	L–M	H	H	Y	Y	Relative (W/kg) and absolute power (W)
Speed	L–M	Y	Y/N	M–H	H	H	Y	Y	Speed measures (m/s, m/min, km/h)
Acceleration	L–M	Y	Y	L	H	H	Y	Y	Acceleration measures (m/s^2)
Functional neuromuscular tests	L–M	Y	Y/N	M	M–H	H	Y	Y	Countermovement-jump and drop-jump measures
Acute:chronic-workload ratio	L–M	Y/N	Y	M	M–H	M–H	Y	Y	Size of acute training load relative to chronic load
GPS measures	M	Y	Y	M	M–H	M	Y	Y	Velocity, distance, acceleration, time in zones, location
Metabolic power	M	Y	Y	L–M	L–M	M	Y	N	Energy equivalent
Time–motion analysis video (automated)	H	Y	Y	L	M–H	M	Y	Y	Velocity, location, acceleration
Time–motion analysis video (nonautomated)	M–H	Y	Y	L	M–H	M	Y	Y	Velocity, location, acceleration
Accelerometry	M	Y	Y	L–M	M–H	M	Y	N	*x-y-z g* force
Player load	M	Y	Y	M	M	M	Y	Y	Single variable in AU (time dependent)

Abbreviations: L, low; M, medium; H, high; Y, yes; N, no; AU, arbitrary units.
[a]Measures of training response.

Figure 11: Common Athlete Load Monitoring Quantification Methods summarised by Bourdon, Cardinale et al. (2017)

The quantification of physical loads in rugby union has historically presented specific challenges. These challenges stem from the variety of activities involved in playing rugby union such as interspersed high and low intensity running and collision events, as well as individualised training and positional demands including kicking, passing, rucking, lineouts, gym and other cross-training methods (Quarrie, Raftery et al. 2017). Of further consideration for academy rugby union players is the potential to be participating in several other sports and physical education activities, age-related lifestyle factors, and a remote-athlete status. Bourdon, Cardinale et al. (2017) in their consensus statement suggest that youth athletes specifically are recommended to keep ‘training diaries’ in order to capture the wide-ranging loads they are exposed too alongside recordings of intensity, and if realistic, other more specific measures such as jumps, speeds and weights.

2.6.3 Step 2: Monitoring the Athlete’s Response to Load

The purpose behind monitoring an athlete’s response to load exposure is to obtain information regarding the effectiveness of sports preparation strategies, the readiness to repeat these, and whether the desired adaptation and recovery is occurring. As with measures of load itself, monitoring the athlete's response to load can be achieved through a range of approaches. The approaches can range from simple observations and training diary reflections, to that of more detail-driven questionnaires and invasive measures of blood, saliva and oxygen samples (Bourdon, Cardinale et al. 2017). Bourdon, Cardinale et al. (2017) again as part of their consensus statement on managing athlete loads provide a review of common practices and implementation procedures as part of monitoring the athlete's response to load. Considered 'internal measures' as they are quantifying the athlete's individual response and perceptions of coping with the load imposed on them, the methods reviewed can be captured via both objective and subjective means (Figure 12). In a more detailed systematic review, Saw, Main et al. (2016) summarised these objective and subjective measures during and post activity. Objective measures assessed included heart rate, oxygen uptake, endocrine, blood and immunological responses. These measures provide great detail and objectivity, however, require the use of specific equipment technology and invasive procedures. Subjective methods reviewed were coach or athlete ratings of mood, life stress, and fatigue as derived from wellness questionnaires and psychological inventories. These measures provide a simple and efficient means to capturing the athlete's response to training and require very little equipment and training to implement, however depending on the length and complexity of the inventory may take time to learn and complete. Using a combination of measures as with load capture was deemed the most useful approach with subjective methods tending to be more sensitive to global changes in training and competition loads, while objective methods helped explain the particular bio-motor adaptations e.g. an increase training load resulted in changes in self-reported fatigue but after rest, increases in oxygen uptake were observed resulting in a positive training response and adaptation (Saw, Main et al. 2016).

Method	Cost	Hardware needed	Software needed	Ease of use	Valid	Reliable	Used to interpret	Used to prescribe	Variables
Internal Measures									
RPE	L	N	Y/N	H	M–H	M–H	Y	Y	Single variable in AU (time dependent)
Session rating of perceived exertion	L	N	Y/N	H	M–H	M–H	Y	Y	Single variable in AU (time dependent)
TRIMP[4]	L–M	Y	Y	M	M–H	M–H	Y	N	Single variable in AU (time dependent)
Wellness questionnaires*	L	N	Y/N	M–H	M	M–H	Y	Y/N	Ratings, checklists, AU scale measures
Psychological inventories (eg, POMS, Rest-Q-Sport)*	L–M	N	Y/N	M–H	M–H	M–H	Y	Y	Ratings, checklists, AU scale measures
Heart-rate indices	L–M	Y	Y	H	H	M–H	Y	Y	Heart rate, time in zones, HR variability/recovery measures, etc
Oxygen uptake	H	Y	Y	L	H	H	Y	Y	VO_2, metabolic equivalents
Blood lactate	M	Y	Y/N	M	H	H	Y	Y	Concentration
Biochemical/hematological assessments	M–H	Y	Y/N	L	H	M–H	Y	Y	Concentrations, volumes

Abbreviations: L, low; M, medium; H, high; Y, yes; N, no; AU, arbitrary units.
*Measures of training response.

Figure 12: Common Athlete Response Monitoring Quantification Methods summarised by Bourdon, Cardinale et al. (2017)

Subjective, self-report methods are of particular relevance to this review as they can be completed remotely. Internal, self-report methods such as Rate of Perceived Exertion (RPE) and its global, session based equivalent Session-RPE are unique measures as they have been used to not only quantify the intensity and duration of load exposure, but also give indications as to the acute, biopsychosocial athlete response (Foster, Florhaug et al. 2001, Scott, Black et al. 2013, Haddad, Stylianides et al. 2017). It has been suggested that Session-RPE could be considered as a stand-alone measure for capturing load and monitoring the response, however, the addition of other self-report inventories that capture aspects of life, and school stress, sleep function and physical fatigue may provide more targeted insight into the athlete's load-response relationship (Haddad, Stylianides et al. 2017, Impellizzeri, Marcora et al. 2019).

2.6.4 Step 3: Injury Surveillance

Injury surveillance requires the ongoing, systematic collection and reporting of injury data (Shaw, Orchard et al. 2017). The data collected describes the occurrence of, and factors associated with injury and represents the first stage of any systematic approach to injury prevention (Finch 1997). In sporting research though, 'ongoing and systematic' injury data collection is still somewhat rare (Shaw, Orchard et al. 2017). A 2015 systematic review by Ekegren, Gabbe et al. (2016) identified publications showing current injury surveillance systems and assessed them for quality control (validity and reliability practices). The information extracted from the systematic searches included methodological details, methods used to evaluate data quality and the results of these evaluations. The search found thirty publications, detailing fifteen ongoing injury surveillance systems (Table 2) of which a majority (73%) were within professional or elite settings (11 out of 15). From the fifteen identified systems only seven (47%) provided publications relating to data quality and only four (27%) validated their systems against another alternative source. The review identified a knowledge gap when considering the disproportionate availability of injury surveillance data between the professional elite settings and that of the non-elite settings (youth, amateur, community). The researchers also noted that the appropriateness of overarching operational definitions across sports may not consider the contextual differences at the different levels/grades of each sport. An example of this is within the academy rugby union setting whereby the athletes are considered 'remote' and thus do not generally train in the same place or even with the same coach (Phibbs, Jones et al. 2017). Collecting robust injury surveillance data from this population is therefore problematic given the proximity of the players to the practitioners collecting it. The study also acknowledged that of the select few surveillance systems currently operational across sport, even less have transparent quality controls in place to ensure validity and reliability.

Table 2: Existing Injury Surveillance Projects in Sport

Injury Surveillance Systems	Data Quality Publications	Validation Publications
1. **The National Football League's (NFL) Injury Surveillance System (Deubert, Cohen et al. 2017)**	NO	NO
2. The National Collegiate Athletic Association (NCAA) Injury Surveillance System (Kerr, Dompier et al. 2014)	YES	YES
3. The Australian Football League (AFL) annual injury survey (Saw, Finch et al. 2018)	YES (Not published)	YES (Not published)
4. The Fairfax County Public School System Injury Surveillance Database (Dick, Agel et al. 2007)	NO	NO
5. The Fe´de´ration Internationale de Football Association (FIFA) surveillance system (Junge, Dvorak et al. 2004)	YES	NO
6. The Cricket Australia injury survey (Orchard, Newman et al. 2005)	NO	NO
7. The Union of European Football Associations (UEFA) Champions League Injury Study (Hagglund, Walden et al. 2005)	NO	NO
8. The Norwegian professional football league (Tippeligaen) injury reporting system (Bjorneboe, Florenes et al. 2011)	YES	YES
9. The England Professional Rugby Injury Surveillance Project (Cross, Williams et al. 2018)	YES	NO
10. The National High School Sports-Related Injury Surveillance System (Yard, Collins et al. 2009)	YES	YES

11. The International Ski Federation (FIS) Injury Surveillance System (Bere and Bahr 2014)	YES	YES
12. The International Association of Athletics Federations (IAAF) surveillance system (Alonso, Junge et al. 2009)	YES	NO
13. The International Olympic Committee (IOC) injury surveillance system for multi-sports events (Junge, Engebretsen et al. 2008)	YES	NO
14. Athletic Training Practice-Based Research Network (AT-PBRN) (Lam, Snyder Valier et al. 2015)	NO	NO
15. The Major League Baseball Injury Surveillance system (Drakos, Domb et al. 2010)	NO	NO

Of the fifteen surveillance systems identified in the systematic review by Ekegren, Gabbe et al. (2016) six were from one of the football-based codes (rugby, American football, football/soccer, Australian Football, Gaelic football). Given this representation, another systematic review by Shaw, Orchard et al. (2017) specifically sought to identify publications presenting methodological details of injury surveillance systems in the professional football codes. The review extracted demographic, player/team coverage, injury definition and collection methods, but did not include data quality evaluations. From the review, seven injury surveillance systems were identified, five of which were represented in the review by Ekegren, Gabbe et al. (2016) (FIFA, UEFA, PRISP, NFL, AFL) and two, the National Rugby League, Australia (NRL) and the Gaelic Athletic Association (GAA) that were not. Their findings demonstrated that a range of surveillance methods and definitions are being employed across different football codes, with variations in who records the data, the data recording tool and the dissemination of the data. This has implications such as carefully identifying who and how data is recorded, that the definitions are specific to the football code, clear and understood and that the capture tool is appropriate for the setting. Understanding the sport in question and the particular methods of surveillance that work best will improve injury surveillance outcomes. As a starting point, Verhagen and Van Mechelen (2010) suggests that sports endeavour to contextualise their injury surveillance practices together with four key criteria levels. Alongside a theoretical definition such as previously stated for rugby union, operational definitions should describe 1) the conditions counting as an injury, 2) how the severity of the injury should be measured 3) how the injury should be classified in terms of location and pathology, and 4) what the underlying cause of the injury was. Clarifying the injury surveillance operational definition, severity, classification and underlying cause are therefore considerations for capturing and quantifying injury surveillance data.

2.6.4.1 Injury Definition

The Rugby Football Union's (RFU) longstanding professional rugby injury surveillance project (PRISP) employ a '>24-hour time-loss' injury definition whereby injuries are recorded if a player sustains an injury that results in them being unable to participate in rugby training or matches for more than 24-hours post injury event (Cross, Williams et al. 2018). This data is recorded by medical professionals using a modified Orchard Sports Injury Coding System (OSICS) (Orchard, Rae et al. 2010) at each professional club, then integrated into an online system and reported by researchers as match and training injuries per 1000 player-hours in accordance with the rugby union consensus statement (Fuller, Molloy et al. 2007). The reliability of using a >24-hour time-loss definition across multiple teams, however, is questionable. The potential between-team reporting motivations as well as particular biases towards factors that result in whether a player is not available for 24-hours (general fatigue, scheduling changes, session type, personal reasons) could mean reporting is vastly different between teams. Over a 2-year period the Australian Football League (AFL) detailed substantial differences in between-team variation (CV; 34% - 101%) when comparing a more inclusive definition similar to that of rugby union (any injury resulting in training or match loss) (CV; 101%) to a more restrictive definition (any injury resulting in a missed-match) (CV; 34%) (Saw, Finch et al. 2018). This suggested a more restrictive definition (missed-matches) was more reliable in multi-team settings such as the AFL. The drawback of a more restrictive definition is the potential to underestimate injury patterns as a result of not including injuries resulting in less than 7-days and to over emphasise injuries that may occur in close proximity to a match which may be minor in terms of overall severity and time-loss (Hodgson, Gissane et al. 2007). A reliability study by Cross, Williams et al. (2018) on the Rugby Football Union's PRISP dataset showed that a large proportion of injuries (approximately 50% match and 40% training) had a severity of less than 7-days. When comparing the between-team variation of reporting using the more inclusive definition (more than 24-hour time-loss) compared to the more restrictive (more than 7-day time-loss) the variation was only 10% (CL; 90%). It was considered by the researchers that while the reliability was indeed better for the more restrictive definition as reported previously in AFL, the variation was far smaller, and it was deemed the benefit to understanding injury patterns in greater detail through capturing up to 50% more injuries, outweighed the relatively small improvement in reliability. This also suggests the reliability of different definitions may be contextual. The range of definitions employed by football organisations in the injury surveillance practices reported by Shaw, Orchard et al. (2017) may be to suit their particular environments and research objectives. It is however unknown whether the more inclusive injury definition utilised by English Rugby can scale effectively to the remote-athlete academy settings where potentially definition used by the AFL could be more practical.

Investigations into youth sports injuries show that up to 30% of team sport injuries are considered 'overuse' related (Theisen, Frisch et al. 2013). The investigations by Theisen, Frisch et al. (2013), however, do not include rugby and literature citing these injuries in youth rugby settings in limited (Till, Weakley et al. 2020). The previously mentioned congested sports schedules and stressors alongside the higher associated injury rates with rugby union compared to other sports could mean overuse injuries may be higher in academy rugby union cohorts. Overuse injuries can be defined as 'injuries without a specific, identifiable event responsible for their occurrence of which may not initially result in time-loss but are considered as restricting performance' (Clarsen, Myklebust et al. 2013). While the Professional Rugby Injury Surveillance Project (PRISP) have shown the rationale behind not using a 'missed-match/>7-day time-loss' definition, the >24-hour time-loss definition may still substantially underestimate the incidence and impact of 'overuse' type injuries that do not 'immediately' lead to time-loss. In developing a specific overuse injury questionnaire and reporting system (Oslo Sports Trauma Research Centre - OSTRC Overuse Injury Questionnaire) Clarsen, Myklebust et al. (2013) were able to demonstrate using an injury prevalence metric (number of reported injuries divided by the number of respondents) that of the 75% of athletes identified as reporting overuse injuries, only 11% lead to >24-hour time-loss classification. This has important implications for not only accurately describing the overall injury problem and associated costs, but also tracing the potential long-term, cumulative effects of these overuse injuries. For example, of the total 419 overuse injuries detected as part of the OSTRC Overuse Injury Questionnaire, 142 were classified as 'substantial overuse problems' (moderate or severe perceived reduction in sports performance, participation, or time-loss). Only 40 of these immediately lead to >24-hour time-loss. By exclusively using a time-loss definition, not only were they underestimating the overuse injury problem but also not accounting for the associated cumulative reductions in performance and/or selected training exposures over time e.g. an athlete may participate in the main session for the day but then be strategically removed/rested from others because of restrictions meaning their status is compromised but not flagged under the >24-hour criteria – if this continues over days, weeks or months the associated costs would exponentially accrue. This has particular relevance to academy athletes and their potential to accrue overuse injuries over time that lead to more substantial and potentially career ending and/or long-term functional impairments in the future. Considering overuse injuries within inclusive injury definitions is therefore warranted for youth athlete cohorts.

2.6.4.2 Injury Severity

The severity of an injury relates to the 'cost' to an individual, calculated in either monetary terms (loss of earnings due to injury) or more commonly in sport, time-loss (hours, matches, training sessions lost due to injury) (Verhagen and Van Mechelen 2010). Injury severity is part of assessing the magnitude of the injury problem and improves the validity and reliability of definitions by describing a) the minimal inclusion criteria for an injury to be reported and b) the degree to which injury has affected the population being studied (Verhagen and Van Mechelen 2010). A hierarchy is used when reporting injury severity, namely; tissue damage, time-loss, match/training loss, hospitalisation, catastrophic and fatal (Verhagen and Van Mechelen 2010). The severity criteria adopted from the hierarchy can therefore significantly affect the mean and medium occurrences and severities reported in a study e.g. if using tissue damage as an inclusion criteria, the number of injuries will be high, mean and median severity values will be low and the distribution of injuries will be biased towards muscle injuries; whereas if hospitalisation is used, minor injuries will be filtered out and only more severe injuries recorded, thus the opposite will occur with a distribution bias towards serious joint and bone injuries. The severity of an injury according the rugby union consensus statement (Fuller, Molloy et al. 2007) utilises a time (days) lost from competition and training criteria. This is calculated by summing the number of days from injury occurrence to the player's full return to participation in team training and availability for match selection. Once severity is calculated injuries can be grouped as slight (0-1 days), minimal (2-3 days), mild (4-7 days), moderate (8-28 days), severe (>28 days), 'career ending' and 'non-fatal catastrophic injuries'. This allows researchers and practitioners to identify particular types of injury that are causing a large proportion of the total time-loss and focus injury prevention strategies.

2.6.4.3 Injury Incidence

Injury incidence is a product of both defining what constitutes an injury and then using this definition to describe the extent of the injury problem given a consistent level of exposure or particular population, such as that represented through athlete load (Phillips 2000). Together with severity it is an important metric in both connecting injury surveillance to athlete monitoring and translating the current negative effects of injury within the sporting environment. Incidence can be expressed as 'rates' or 'proportions' whereby the number of injuries experienced (numerator data) is combined with a suitable measure of exposure to sports activity (load) (denominator data) e.g. seasons, matches, training sessions or playing-hours, or for a proportion the total population in question e.g. regional academy rugby union players (Phillips 2000). Whilst absolute numbers and proportions can be used to describe the magnitude of injury occurrence, these figures' numerator data are included as a subset of the denominator data. This means that absolute numbers and proportions disregard contextual factors such as the degree of exposure to particular injury-related events which can a) distort the amount/type of injuries captured and b) make it difficult to identify contributing factors (Brooks and Fuller 2006). The incidence of injury does, however, account for levels of exposure, and thus is the most basic expression of risk (Phillips 2000). This is most consistently reported in injury prevention research as injuries 'per 1000 player-hours' (how many injuries one player might expect after 1000 hours of participation) and 'per 1000 athlete-exposures' (injuries per athlete per 1000 matches or training sessions) (Brooks and Fuller 2006). For incidence to be reported effectively it is important that the selected measure of exposure be accurately collected. While more time consuming, displaying incidence rates in relation to 'player-hours' is generally favoured over 'athlete exposures' as it allows for greater depth of analysis (Knowles, Marshall et al. 2006). Athlete exposures may, however, be favoured in sports such as American Football, where large playing squads and sporadic training and competition schedules make player-hours hard to quantify (Kerr, Dompier et al. 2014). In remote-athlete contexts such as academy rugby union, incidence can be used in connection with load measures and athlete monitoring to detail a load-response-injury relationship. What is however unclear, is how to manage the contextual barriers of remote-athlete settings while maintaining the data capture quality and quantity needed to display meaningful insights. Injury definitions, their severity and incidence measures are all heavily reliant upon clinical support and diagnosis. Given the access barriers present within remote athlete settings and the detail within current injury surveillance best-practices, the lack of reasonable and contextual solutions to capturing injury data in these populations could explain the dearth of research identified by Ekegren, Gabbe et al. (2016).

2.6.5 Summary of Quantifying Load-Response-Injury Interactions:

- The load imposed on an athlete can be both sport and non-sport-related and come from both physical and non-physical sources. Sources of load unique to academy rugby union athletes could include school and physical education, multi-sport and level competition and training, and elements of growth, maturation and social-peer interaction.
- Capturing athlete loads should consider the wide variety of load sources specific to program and environmental constraints. Ideally utilising a combination of methods and variables that explain the frequency, intensity, volume/duration and type/mode of loads expressed individually and cumulatively is recommended. Variations of training diaries and objective counts of specific activities are suggested as a starting point for youth athletes.
- Methods to capture the athlete's biopsychosocial responses to load can be both objective and subjective. Subjective measures such as training diaries, wellbeing questionnaires and psychological inventories provide seemingly the most viable options for remote-athlete academy rugby union players.
- Approaches to best practice injury surveillance should consider criteria-driven operational definitions that include overuse injuries, and how best to connect and translate data to athlete load and response monitoring. Understanding who captures and interprets metrics relating to the injury definition, severity and incidence can help guide injury surveillance best-practice.
- Key considerations for selecting the right quantification methods for athlete monitoring and injury surveillance are the time, cost, equipment, reliability, validity, ease of use and standard of competition and staff available. Overcoming access barriers to remote-athletes and how this impacts current data quality, quantity, quantification and capture methods that rely on professional staff is considered a major reason behind the dearth of available data on remote, youth athlete populations.

2.7 Capturing Remote-Athlete Biopsychosocial Load-Response-Injury Data

2.7.1 Self-Report Measures

Given the implementation challenges highlighted within the athlete monitoring and injury surveillance research (Ekegren, Gabbe et al. 2016, Bourdon, Cardinale et al. 2017, Gabbett, Nassis et al. 2017), a particular suite of methods called 'athlete self-report measures' have becoming increasingly popular within research and practice (Gallagher, Needleman et al. 2017, Saw, Kellmann et al. 2017). Utilising established psychology and sociology research into the load-response-injury relationship (Williams and Andersen 1998, Galambos, Terry et al. 2005, Wiese-Bjornstal 2010, Ivarsson, Johnson et al. 2017), recent reviews have described these adapted athlete self-report measures, as consisting of a combination of short, written reflections and/or multiple-choice questions (Gallagher, Needleman et al. 2017, Saw, Kellmann et al. 2017). They generally employ some form of Likert scale e.g. rate your level of agreement from 1-3 (1 = no agreement and 3 = full agreement) and are specifically designed for either construct purposes (specific physical or psychological states e.g. fatigue or mood) or ecological purposes (specific to the sport or time-constraints e.g. specific anatomical sites for muscle soreness linked to performance within shorter more precise surveys to fit into applied practice settings). (Saw, Main et al. 2016). The accessibility and potential to monitor both sport and non-sport related loads, responses and outcomes, means they not only provide an attractive option for many levels of sport, but are also heavily represented within studies assessing load-response-injury interactions (Jones, Griffiths et al. 2017). Given this suite of methods are now being marketed as short, custom designed measures for daily completion, their specific use in remote-athlete settings within digitised and mobile-app based solutions is also becoming increasingly favoured by practitioners and researchers (van Mechelen, van Mechelen et al. 2014, Soomro, Sanders et al. 2015, Sadeghi and Alizadeh 2017, Düking, Achtzehn et al. 2018, Hamlin, Wilkes et al. 2019, Soomro, Chhaya et al. 2019). While athlete self-report measures can offer simplicity, affordability and scalability advantages over other more traditional, lab-based physiological methods and long form clinical psychological enquires (Main and Grove 2009, Halson 2014, Saw, Main et al. 2016, Noon, James et al. 2018), it has also been questioned as to how sensitive, valid and reliable some of these measures are (Burgess 2017) and whether more insightful objective measures can be harnessed with advances in technology (West, Williams et al. 2019). The following section will now provide a review of specific athlete self-report measures that have application within remote-athlete development pathways such as academy rugby union as well as insight into how mobile health applications are supporting the capture of data.

2.7.2 Session-RPE Load

The session rate of perceived exertion (Session-RPE) method is the product of an athlete's 'perceived rate of exertion' as recorded by the subjective 'Session-RPE scale' (Figure 13) and the duration of the session recorded in minutes (Halson 2014). It is one of the few global and adaptable methods to quantifying load as it requires no specialised training or equipment to administer and can be used across any activity type. The use of Session-RPE is considered widespread in rugby union with 95% (n=20) of professional clubs reporting its use and 95% of the cohort considering it an effective means of monitoring athlete load (Comyns and Hannon 2018). While more recent investigations have found that the perceived value of Session-RPE within professional rugby union has waned with greater access to other more objective technologies such as Global Positioning Systems (GPS) (West, Williams et al. 2019) the practicality of the method means it is still widely used, especially in non-professional settings. First developed by Carl Foster (Foster, Florhaug et al. 2001) it asks the athletes to rate the global intensity of the session utilising a specialised Session-RPE scale with verbal anchors (Figure 13) that translates the athletes perception of effort into a numerical score between 0-10. This scale should not be confused with Borg (1974) category ratio (CR) 0-10 rate of perceived exertion scale. The Session-RPE scale uses slightly different vernacular modified to suit American English idiosyncrasies (e.g. light becomes easy; strong or severe becomes hard) and, whereas Borg's CR 0-10 scale is used throughout specific time-points of the activity, the Session-RPE scale is used after the sessions completion representing a measure for the entire session (Foster, Florhaug et al. 2001). The result is a single arbitrary unit (AU) representing the total workload for that session.

E.g. A training session duration of 60-minutes, multiplied by a Session-RPE of 5 (somewhat hard) equals a training load of 300 AU (Foster, Florhaug et al. 2001).

HOW WAS YOUR WORKOUT DURING THE SESSION?

Rating	Descriptor
0	NOTHING AT ALL
1	VERY, VERY EASY
2	EASY
3	MODERATE
4	SOMEWHAT HARD
5	HARD
6	
7	VERY HARD
8	
9	
10	MAXIMAL

Figure 13: Session Rating of Perceived Exertion Scale developed by Foster, Florhaug et al. (2001)

A review by Haddad, Stylianides et al. (2017) set out to 1) retrieve all the data validating the Session-RPE Method using various criteria, 2) highlight the rationale and ecological usefulness, and 3) describe factors to consider when utilising the method between 2001 and 2016. A total of 950 studies cited the original Foster, Florhaug et al. (2001) study and 36 of those had investigated the validity and reliability of the Session-RPE method. The researchers found that the Session-RPE method presented a cheap, simple and non-invasive method for quantifying and monitoring load, with its use as a practical tool being backed by strong correlations between other objective methods. When compared against summated heart-rate zone criterion scores for steady state and intermittent aerobic activity (cycling, running, rowing) (Foster, Florhaug et al. 2001), where correlations ranged between r = 0.75 and r = 0.90 suggesting Session-RPE is a valid and reliable representation of physiological heart-rate derived session intensity and stress (r = coefficient of correlation; the strength and direction of relationships between variables where -1 and +1 represent high negative or positive linear relationships). A similar relationship has been observed for resistance type training in the gym, where several compound and isolated resistance training exercises were used to compare Session-RPE against objective 1-repetition maximum percentages of 50%, 70% and 90% (r = 0.88) (Day, McGuigan et al. 2004). This shows the versatility of the Session-RPE measure across multiple intensity and activity types. Using a specific summated heart-rate method for quantifying workload called a ‘training impulse or TRIMP’ Clarke, Farthing et al. (2013) compared Session-RPE across 11-weeks and 713 practice sessions with 20 collision sport athletes. Correlations ranged between r = 0.69 and 0.91 prompting the researchers to conclude that Session-RPE represented a highly practical and accurate method for quantifying workload in collision sports. These findings have been supported specifically across multiple studies in rugby league (Lovell, Sirotic et al. 2013) and ecologically validated in rugby union (Comyns and Flanagan 2013). Session-RPE has the ability to capture a broad variety of biological (physical and physiological stressors), psychological (cognitive and non-physical stressors and appraisals) and social (peer and societal influences). It can be used to describe the frequency, intensity, volume/duration and type/mode of stressors imposed on athletes, and as it is both individual, and perceptual, can consider sub-conscious appraisals of the current situation and external environmental (peer group pressure, anxiety, weather). It can therefore be suggested as one of the only true biopsychosocial load capture methods currently available.

Various factors have been proposed as potentially affecting perceived exertion including individual characteristics (personality, age, fitness, expertise), music, video, temperature and caffeine however the exact effect is not entirely understood (Haddad, Stylianides et al. 2017). This could be one reason to explain the levels of variance between correlations. The timing in which the Session-RPE method is utilised could also alter the reliability of recordings. Foster, Florhaug et al. (2001) proposed completing measurements 30-minutes after the sessions completion as this was anecdotally seen to neutralise particularly hard or easy parts of the session at the end dominating the subject's ratings. Specifically, within youth athletes it has been suggested that the Session-RPE method should be used with caution given it is considered that these athletes may not yet have the knowledge and self-awareness to self-assess their perception of effort (Bourdon, Cardinale et al. 2017). This, however, is a debatable point given the measure is supposed to be subjective and based on what the individual perceives the intensity to be. Researchers have attempted to investigated these concerns. Phibbs, Roe et al. (2017) tested the level of agreement between the criterion measure of Session-RPE (30-minutes post session) and that of a web-based survey completed up to 24-hours after the session with thirty-six academy rugby union players ranging from 16 to 18-years. The authors found nearly perfect correlations (r = 0.87 [0.78-0.93]) and small typical error of the estimate (4.3% [3.6-5.4]) suggesting that not only was Session-RPE a valid and reliable measure of load for youth athletes but that it could be used as part of a web-based online survey up to 24-hours after the session's completion. The authors noted that these athletes were prepared and practiced in using the measure, prompting the notion that while caution is advised for youth athletes this can be lessened with adequate familiarisation. Of particular note, there are other load measures that do not generally correlate as well with Session-RPE such as high-speed running, and acceleration counts and distances (Lovell, Sirotic et al. 2013). This seems to be highly variable and potentially sport specific (Haddad, Stylianides et al. 2017) meaning that while Session-RPE represents a feasible universal approach, combining it with other measures may help explain some of the variability and improve the specificity.

Across sports and levels, findings from the International Olympic Committee's review into the load-response-injury relationship found that Session-RPE was one of the most frequently used measures of load, particularly in team-based sports (Soligard, Schwellnus et al. 2016). The fundamental significance of the measure within rugby union is also supported by Quarrie, Raftery et al. (2017) in their load-response-injury consensus statement whereby they state Session-RPE and exposure time at a minimum should be used to capture load within professional rugby union. Session-RPE is also favoured as a measure within the few studies that describe the loads associated with remote-athlete, academy rugby union players (Phibbs 2017, Phibbs, Jones et al. 2017, Phibbs, Jones et al. 2018). The measurement of load through Session-RPE is therefore considered an adaptable, valid and reliable load measure across multiple sports, activity types and age groups. It is a unique measure as perceived biopsychosocial sources of load can all be incorporated and combined with an objective measure of session duration. While it may not be the most sensitive measure for every situation and variable, it can statistically account for a large majority of variance across a more comprehensive selection of activities than any other current load measure therefore making it a fundamental measure to consider for remote-athlete, academy rugby union.

2.7.3 Wellbeing and Life Stress Questionnaires

The term 'wellbeing' in sports science covers a broad range of inventories that attempt to assess how athletes are perceiving their current biopsychosocial life stress and fatigue state (Jones, Griffiths et al. 2017). The term wellness, noted in this review within quantification methods of athlete response, rightly or wrongly is generally used interchangeably with wellbeing within the sporting literature. While there appears to be no clear consensus on the delineation between wellbeing and wellness, wellbeing is considered a broader concept and thus encompasses wellness (Dodge, Daly et al. 2012). Life stress, in contemporary settings, is viewed as an ongoing process whereby an individual is constantly making appraisals of their life, demands being placed on them, and the situations they find themselves in, and endeavouring to cope (Fletcher, Hanton et al. 2012). While wellbeing tends to be an overarching term, life stress targets the impact of life events and the psychosocial responses to these. Fatigue is another more targeted term that can come under wellbeing. Fatigue within the sports science literature can be defined as the decrease in an athlete's pre-activity/baseline biopsychosocial function (Jones, Griffiths et al. 2017). While self-reported load measures such as Session-RPE help explain the global work performed, situation and exposures an athlete faces, they do not provide comprehensive insight into the subsequent short and longer-term adaptive and maladaptive responses of the athlete. Therefore, self-reported wellbeing and life-stress inventories have been used by practitioners and researchers to compliment athlete load monitoring by accounting for both the physical and non-physical biopsychosocial responses to those loads.

There are various items based upon traditional psychological studies that now make up contemporary wellbeing and life-stress questionnaires. In a meta-analysis by Ivarsson, Johnson et al. (2017) the authors identified that most of the early psychology-based research targeted personality traits and negative life events as key variables to monitor as part of these questionnaires. These inventories grew with the addition of the Williams and Andersen (1998) model of stress and athletic injury which identified an athletes cognitive appraisal and physiological or attentional changes as contributing to the overall stress-response. Finally, in an extension to the model of stress and injury, Appaneal and Perna (2014) suggested a biopsychosocial approach whereby aspects of motivation, poor sleep quality and acute psychophysiological fatigue would be addressed. The meta-analysis by Ivarsson, Johnson et al. (2017) also identified that prolonged stress levels relating to negative life events and daily hassles had the strongest relationship with that of injury-risk and performance parameters. The strong emotional distress and possible dysfunction to the neurological networks in the brain associated with prolonged stress and reactions to negative life events was suggested as the mechanism behind these variables. Given adolescence represents a particularly volatile period of growth and maturation, emotions and experiences related to wellbeing and life-stress inventories could represent useful insight into their load-response-injury interactions.

Utilising the key aspects of wellbeing and life-stress identified from traditional psychological studies, more specified questionnaires are now being used within sport. In a recent systematic review into the load-response-injury relationship by Jones, Griffiths et al. (2017) seven studies were identified as using various forms of wellbeing and life stress inventories. Three studies used the 'Daily Hassles and Uplifts scale (HUS)' and found greater daily hassles to be associated with increased injury in elite senior and academy soccer/football players (Ivarsson and Johnson 2010, Ivarsson, Johnson et al. 2013, Ivarsson, Johnson et al. 2014). The HUS is a life stress inventory addressing aspects of relationships, personal and work responsibilities on a four-point Likert scale ranging from 0 (not at all) to 3 (very much). The HUS inventory has a high test-retest reliability (Delongis, Folkman et al. 1988), and reported Cronbach's alpha (coefficient of reliability; how closely related a group of items are as a group, where 0.7 is considered acceptable) ranging from 0.71-0.87 (Lu 1991, Ivarsson, Johnson et al. 2014). The studies identified particularly trait anxiety and negative-life-event stress related to relationships and work/school as a key elements accounting for 24% of the variance with injury risk. Kinchington, Ball et al. (2010) investigated subjective physical fatigue and found that poor scores on the Lower-Limb Comfort Index (LLCI) were correlated to increased injury risk in contact-sport athletes ($r = 0.77$-0.88). The LLCI asks athletes to rate comfort levels for different anatomical areas on a 1-7 Likert scale and is considered a valid and reliable indicator of muscular discomfort over time, across rugby and football/soccer environments (Kinchington, Ball et al. 2010). Using the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) which combines both aspects of life-stress (coping with relationships, socialising and academic study/other work) and physical fatigue markers (sleep, muscular soreness), Laux, Krumm et al. (2015) also found associations with injury risk. A generalised linear model with exposure represented by the RESTQ-Sport inventory and the outcome being injury, showed questions relating to Fatigue (OR 1.70, $P=0.007$), Disturbed Breaks (OR 1.84 $P=0.047$) and Sleep Quality (OR 0.53 $P=0.010$) significantly predicted injuries in the month after the assessment (OR = Odds ratios; a measure of association between an exposure and an outcome, where ratios >1 suggest higher odds of outcome given an exposure and <1 lower odds). While the previously mentioned five studies showed associations between increased physical and psychological fatigue, life stress and decreased sleep and an increase in injury risk, the remaining two studies, while still providing an association, showed the opposite. Killen, Gabbett et al. (2010) used a bespoke questionnaire which asked athletes to rate levels of sleep, food, energy, mood, and stress on a scale of 1-10 (1 being extremely poor and 10 being excellent) bi-weekly. They found that increased subjective, acute physical and psychological wellbeing measures from the questionnaire yielded a decreased risk of injury (r = 0.71 P=0.08). Similarly, King, Clark et al. (2010) showed increased perceptual fatigue (measured by fatigue and lack of energy factors from RESTQ-Sport) was associated with decreased sports performance training injuries and match time-loss injuries. Both authors suggested that the unexpected findings could be because when players consider themselves less fatigued, they may train/compete at higher intensities and are more likely to be involved in potentially injurious events (Killen, Gabbett et al. 2010, King, Clark et al. 2010).

One of the major criticisms aimed at self-report measures has been that they may not provide the sensitivity needed compared to more traditional physiological assessments. A review by Saw, Main et al. (2016) specifically sought to compare the utility of self-report methods versus objective physiological methods (e.g. heart-rate, blood, oxygen) for monitoring the athlete's response to load. They found fifty-six original studies pre-May 2014 showing; 1) self-report and objective methods generally did not correlate and 2) self-report markers were more sensitive and consistent at reflecting acute and chronic changes in load. A dose-response relationship was evident between load and subjective ratings of stress and fatigue whereby, as load increased so did subjective stress and fatigue ratings. The review therefore showed that while subjective and objective methods were probably monitoring different aspects of the workload response, self-report methods were superior in reflecting changes in load and, if appropriately designed, could help explain how load was specifically influencing e.g. muscular fatigue, anxiety. This relationship and increased sensitivity has also been shown more recently within an academy rugby union population (Noon, James et al. 2018). In a counterbalanced crossover design, thirteen academy rugby union players were exposed to both low load and high load physical activity and monitored using both objective (heart rate and counter-movement jump) and a self-report wellbeing questionnaire (training motivation, sleep quality, recovery, appetite, fatigue, stress and muscle soreness). The study found the wellbeing questionnaire was superior in detecting both group and individual responses to load. Selected wellbeing measures of motivation, sleep quality and muscle soreness displayed large to moderate reductions (effect sizes) following high load sessions compared to low. While the study did not account for other non-physical-activity related stressors, the research was performed in a controlled, and easier period of the season so as additional training did not influence results. Wellbeing items such as fatigue, stress and appetite were not sensitive to load changes despite previous research showing that they were (Gastin, Meyer et al. 2013). It could be suggested that these items are more specifically useful during the competitive season, which was a difference between the two studies, thus keeping these items within future questionnaires may still hold merit.

While there are several sports-specific wellbeing and life-stress inventories that have been validated and undergone robust reliability procedures (Raedeke and Smith 2001, Kellmann 2002, Main and Grove 2009, Villanueva, Bennett et al. 2010) a limitation of these is that they lack ecological validity e.g. they may ask irrelevant/unspecific questions for the particular sport or athlete and may be too time consuming to foster adequate adherence. It has therefore been suggested that practitioners and researchers create bespoke questionnaires using previously valid and reliable methods as guides (McLean, Coutts et al. 2010, Gastin, Meyer et al. 2013, Halson 2014). *Figure 14* provides an example of a subjective wellbeing problems questionnaire for sleep, muscle soreness, stress, fatigue and mood states commonly used in sports settings that was adapted from several other inventories (McLean, Coutts et al. 2010). The scores from each of which are summed to obtain an overall wellbeing score or used individually to ascertain the significance of different aspects of physical and psychological stress and fatigue. Lower scores represent a better sense of subjective physical and psychological wellbeing whereas higher scores indicate a worse sense. The questionnaire can be completed in under a minute, and allows insight into the life-stress and fatigue elements suggested previously as being linked to injury (muscle soreness, energy levels, sleep quality and mood states) within longer questionnaires and showing sensitivity to changes in load in academy rugby union players (Noon, James et al. 2018). Studies using the longer subjective questionnaire versions have previously implemented these weekly and monthly with good reliability (Killen, Gabbett et al. 2010, Kinchington, Ball et al. 2010, Ivarsson, Johnson et al. 2014). The researchers however have all suggested that more sensitive results could be attained with greater questionnaire frequency but have been limited because of the time-consuming nature of these questionnaires. The advantage therefore of the subjective wellbeing questionnaire by McLean, Coutts et al. (2010) is that it can be used daily to monitor athlete’s responses to workload and thus potentially provide more sensitive feedback.

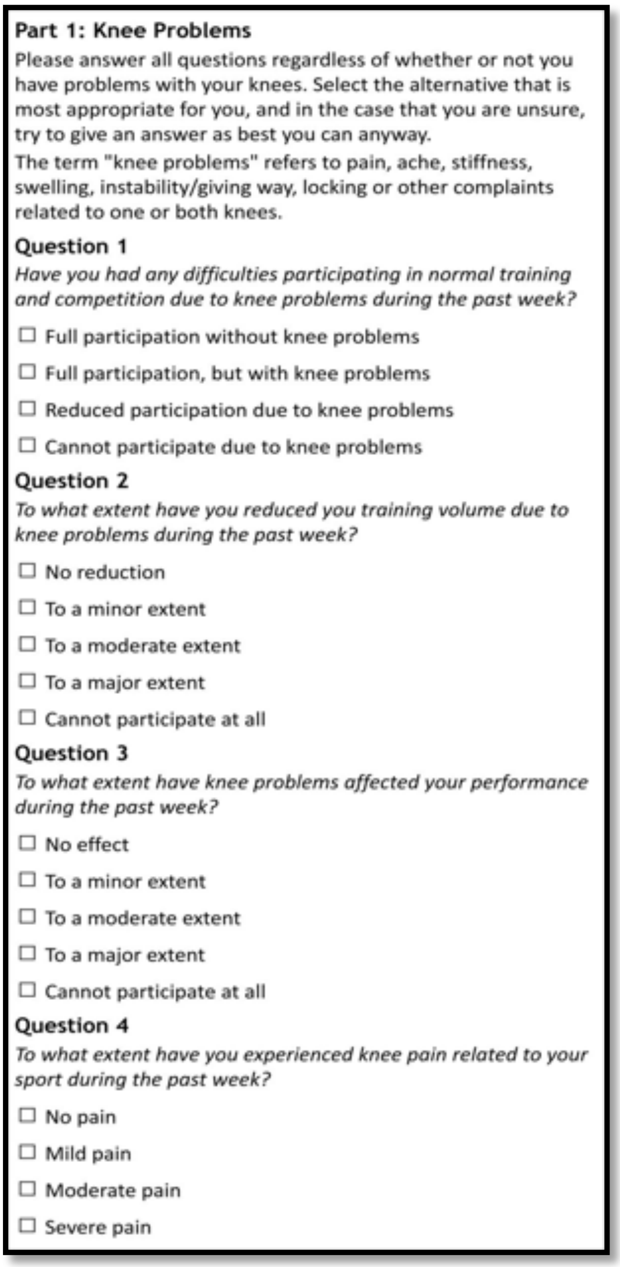
	1	2	3	4	5
FATIGUE	Very fresh	Fresh	Normal	More tired than normal	Always tired
SLEEP QUALITY	Very restful	Good	Difficulty falling asleep	Restless sleep	Insomnia
GENERAL MUSCLE SORENESS	Feeling great	Feeling good	Normal	Increase in soreness/tightness	Very sore
STRESS LEVELS	Very relaxed	Relaxed	Normal	Feeling stressed	Highly stressed
MOOD	Very positive mood	A generally good mood	Less interested in others &/or activities than usual	Snappiness at team-mates, family and co-workers	Highly annoyed/ irritable/down

Figure 14: Subjective Wellbeing Problems Questionnaire developed by McLean, Coutts et al. (2010)

A limitation of the subjective wellbeing problems questionnaire by McLean, Coutts et al. (2010) in Figure 14 is that it is missing some of the important 'life stress' elements (relationships, levels of positivity/ anxiety and academic study) previously mentioned as being linked to injury. Some of the longer questionnaires such as the 'Daily Analysis of Life Demands for Athletes' (Rushall 1990) and Recovery Stress Questionnaire for Athletes (RESTQ-Sport) provide valid and reliable questions surrounding these elements, however, as previously mentioned these are typically time-consuming and thus viewed as inappropriate for regular monitoring in team sport settings (Saw, Main et al. 2016). The addition of some of these specific questions to the subjective wellbeing questionnaire or as another brief questionnaire could therefore strengthen the validity of such questionnaires or monitoring practices to both represent the full spectrum of important elements of life stress but also likelihood of better associations with injury risk. The major question to consider, however, is whether the practical significance of the shorter bespoke questionnaires outweighs the lack of extensive tests of rigor the longer version has. For newly commissioned research with more than one independent factor to consider and time-pressurised subjects it may be considered pertinent to side with the more practical versions to begin with. This is because previous studies have experienced push back initially with the longer versions (Ivarsson and Johnson 2010, Ivarsson, Johnson et al. 2013, Ivarsson, Johnson et al. 2014) and that the more extensive methods could always be layered on thereafter if deeper analysis is warranted.

2.7.4 Oslo Sports Trauma Research Centre Questionnaire

Self-reported injury surveillance is also showing promise. Several studies have proposed ways to combine best-practice injury consensus statements with that of bespoke self-report methods and medical practitioner diagnosis (Møller, Wedderkopp et al. 2017, Sadeghi and Alizadeh 2017, Düking, Achtzehn et al. 2018, Ronnby, Lundberg et al. 2018, Hamlin, Wilkes et al. 2019, Soomro, Chhaya et al. 2019). Valid self-reported outcome measures relating to injury and performance can improve the understanding of these areas within remote-athlete settings. A systematic review into self-reported performance and injury measures in sport by Gallagher, Needleman et al. (2017) identified that while there was no universally accepted measure of performance (mainly due to the wide range of sports and their specific technical, tactical and competitive structures), the Oslo Sports Trauma Research Questionnaire was one such questionnaire for injury surveillance. The Oslo Sports Trauma Research (OSTRC) Questionnaire is an evidence-based self-report injury surveillance method (Clarsen, Myklebust et al. 2013). Athletes report on issues to five body regions: 1) shoulder 2) back, 3) hip and groin, 4) knee and 5) ankle. For each region of the body four questions are posed. These questions can be seen in Figure 15 which presents an example of these for the knee region.



Part 1: Knee Problems

Please answer all questions regardless of whether or not you have problems with your knees. Select the alternative that is most appropriate for you, and in the case that you are unsure, try to give an answer as best you can anyway.

The term "knee problems" refers to pain, ache, stiffness, swelling, instability/giving way, locking or other complaints related to one or both knees.

Question 1

Have you had any difficulties participating in normal training and competition due to knee problems during the past week?

☐ Full participation without knee problems
☐ Full participation, but with knee problems
☐ Reduced participation due to knee problems
☐ Cannot participate due to knee problems

Question 2

To what extent have you reduced you training volume due to knee problems during the past week?

☐ No reduction
☐ To a minor extent
☐ To a moderate extent
☐ To a major extent
☐ Cannot participate at all

Question 3

To what extent have knee problems affected your performance during the past week?

☐ No effect
☐ To a minor extent
☐ To a moderate extent
☐ To a major extent
☐ Cannot participate at all

Question 4

To what extent have you experienced knee pain related to your sport during the past week?

☐ No pain
☐ Mild pain
☐ Moderate pain
☐ Severe pain

Figure 15: OSTRC Questionnaire example questions for the Knee developed by Clarsen, Myklebust et al. (2013)

The OSTRC questionnaire has also been shown to be sensitive and valid in documenting the pattern of both acute and overuse injuries in remote-athletes (Clarsen, Ronsen et al. 2014) which was previously noted as important for youth athlete settings. The relevance to the academy rugby union environment is that stakeholders for this cohort are concerned with long term athletic development, and welfare of these athletes, meaning they need to track how particular schedules and exposures impact athletes over longer periods of time. Overuse injuries could be a major factor to consider in the academy rugby union environment. The potential parental, coach and peer pressures these athletes are perceivably under to compete at not only multiple levels/grades of rugby, but also other sports may give rise to a greater prevalence of overuse injuries. This would mean that a time-loss criterion may mis-represent the impact the competing and highly variable schedules and exposures are having on academy rugby union players. The additional utility of the OSTRC Injury Questionnaire is that it relies upon a weekly self-report method reducing practitioner burden and giving the option for the athletes to report remotely and then be followed up by practitioners over the phone or at the next face-to-face training session. While athlete self-report injury surveillance does not represent medical practitioner diagnosis, the utility of using bespoke surveys to alert and initially inform practitioners to injuries within remote-athlete settings opens up possibilities not previously available in these settings. The combination of self-report athlete monitoring and injury surveillance methods within bespoke, user-friendly, automated systems therefore has the potential to overcome the logistical challenges associated with remote-athlete settings.

2.7.5 Mobile Athlete Self-Report Methods – Smartphone Applications

While the aforementioned self-report athlete monitoring and injury surveillance methods show promise in reducing barriers relating to the need to have access to costly equipment and professional support, the management of traditional paper and manually inputted digital collection modes still poses a barrier to large, remote-athlete cohorts. One of the major barriers to information collection and surveillance in academy rugby union is that players spend a lot of time away from the academy environment, either at their schools, homes, or in transit between multiple commitments (Phibbs, Jones et al. 2018). Through their investigations into the viability of athlete self-report methods, Saw, Main et al. (2015) advocated the use of smartphone application technologies (Apps) as a way of building upon the traditional paper and digitised collection modes. Emerging technologies such as that of mobile health (mHealth) have been suggested as having the potential to revolutionise sports medicine (van Mechelen, van Mechelen et al. 2014, Verhagen and Bolling 2015). This technology uses mobile phone-based computers called ‘smartphones’ and their inbuilt programs called ‘applications’ (Apps) to capture and amalgamate data remotely.

The use of Apps for remote-athlete monitoring and injury surveillance purposes has previously been investigated (Verhagen and Bolling 2015, Düking, Achtzehn et al. 2018), and has already been used in other remote-athlete settings such as cricket, distance running and Gaelic Sports (Sadeghi and Alizadeh 2017, Lyons, OBroin et al. 2018, Ronnby, Lundberg et al. 2018, Soomro, Chhaya et al. 2019). Within academy rugby union, Phibbs, Jones et al. (2018) used an online smartphone-based questionnaire to capture daily training and match Session-RPE loads from academy rugby union players remotely located to the researchers, with no missing data points. The same researchers used a similar web-based survey that could be accessed by athlete's smartphone devices to validate a 24-hour recall Session-RPE measure against a criterion Session-RPE measure taken 30-minutes post training. This protocol again demonstrated full adherence, with the researchers concluding that both the method of collection and the measure were robust and valid in academy rugby union settings (Phibbs, Roe et al. 2017). Injury surveillance research has also utilised this type of technology. The season long 2014/15 Rugby Injury Surveillance in Ulster Schools (RISUS) project implemented a web-based data collection system with text message reminders to improve practitioner injury reporting adherence (Archbold, Rankin et al. 2017). After their review of current injury surveillance methodologies, Sadeghi and Alizadeh (2017) identified smartphone applications as the best way to link injury surveillance practices with the participants, practitioners, and researchers. They subsequently designed a bespoke application that was deemed effective in recording injuries and sending results to the researchers in accordance with the football injury surveillance consensus statement guidelines (Fuller, Ekstrand et al. 2006). Unfortunately, no further assessment criteria of effectiveness were stated apart from the fact the information was successfully inputted and received by the research team, thus future studies could utilise more systematic means of assessing effectiveness.

While there is no considered best practice design in relation to athlete monitoring and injury surveillance smartphone applications, it is gaining both popularity and utility given the large-scale accessibility, ease of use and data collection and organisation capabilities (Düking, Achtzehn et al. 2018). It has been suggested, however, that an appreciation for the requirements in successfully setting up and implementing digital collection and smartphone apps in sport is lacking (Duignan, Slevin et al. 2019). In their investigations into the stakeholder perceptions of the implementation processes behind mobile athlete self-report methods in Gaelic Football, Duignan, Slevin et al. (2019) demonstrated a considerable underestimation of the practical requirements to successful implementation. The authors found that the clarity and understanding of using the procedures and technology, alongside education surrounding why it was being implemented and how, all contributed to this underestimation of requirements. While the sample size (21-participants, 10-players, 11-staff) and the unique nature of Gaelic sports (amateur sport, operating with professional attitudes) may offer limitations to other sports, the remote-athlete status of Gaelic sports is very similar to that of academy rugby union players. Collaborative planning and structured feedback loops connecting all stakeholders to future implementation strategies were considered key to improving understanding and successful use of mobile athlete self-report methods.

Even considering the potential barriers, the application of smartphone apps and digital technology within academy rugby populations is encouraging. The bespoke development of smartphone applications in consultation with participants, practitioners and researchers, based upon accepted athlete monitoring and injury surveillance procedures has great potential utility in the academy rugby union setting for improving; 1) practitioner time burden, 2) access to remote athletes for data input, 3) adherence and longitudinal data capture, and 4) data storage, analysis and feedback efficiency. Published recommendations on the successful implementation and maintenance of these systems, however, suggest a thorough evaluation of the implementation context and the potential facilitators and barriers (Ekegren, Donaldson et al. 2014, Saw, Kellmann et al. 2017, McKay, Cheng et al. 2018).

2.7.6 Summary of Capturing Remote-Athlete Biopsychosocial Load-Response-Injury Data:

- Self-report methods of athlete monitoring and injury surveillance offer accessibility and the potential to monitor both sport and non-sport related loads, responses and outcomes within digitised and smartphone applications.
- Session-RPE presents as the one truly biopsychosocial measure of athlete load and is considered valid and reliable within academy rugby union settings. While it may not be the most sensitive measure for all situations, it is the most adaptable and simple measure to quantify a range of athlete load variables and descriptors.
- Wellbeing questionnaires and the addition of life stress elements relating to school/academic, family and relationships, general sport and aspects of general coping can capture a range of biopsychosocial responses that can be linked to injury-risk along the load-response-injury interaction.

- Self-reported injury, while not a replacement for medically diagnosed injury, shows promise in reducing the barriers to remote-athlete injury data capture. The Oslo Sports Trauma Research Centre Injury Questionnaire can capture both acute time-loss and overuse injuries and is considered a valid and reliable injury surveillance system that can be embedded within digital and mobile phone technologies.

Given the widespread use and access to smartphone application technologies, embedding a range of self-report athlete monitoring and injury surveillance methods within these devices seems a logical next step to reducing the access barriers present in remote-athlete academy rugby union settings. Assessing the processes behind the development and implementation of these systems is therefore an important final step for this review.

2.8 Developing and Evaluating Sporting Implementation Strategies

2.8.1 Understanding the Context

It has been proposed that research evidence alone is insufficient to develop implementable sports innovations (Donaldson, Lloyd et al. 2016) such as App-based athlete monitoring and injury surveillance systems. To address this in the injury prevention research, the Translating Research into Injury Prevention Practice (TRIPP) framework was introduced which built upon the Sequence of Prevention Model with two additional steps; 1) understand the implementation context, and 2) evaluation of the injury prevention intervention (Finch 2006). Both these additional steps relate to an ability to integrate the sporting 'context' in order to make more informed decisions surrounding the development and evaluation of sporting interventions and their implementation strategies. The word 'context' can be defined as 'the interrelated conditions in which something exists or occurs'. The definition implies that the context is of equal importance together with the defined sporting outcome or problem, as for something to exist or occur in the first place, it must also have a context to function. This notion is supported through the ecological dynamics theory that has driven the biopsychosocial approach to this review, whereby environment, task and person interrelate (context) to shape the functional output (Seifert, Araujo et al. 2017). If the context is in fact of equal importance to the evidence, then this poses the question as to why the context-driven steps in the TRIPP framework occur at the end of the staged approach. The first assertion could be that initially the framework's additional steps were added to focus on injury prevention programs that were designed based upon the epidemiological and aetiological evidence captured in previous stages. While credible, this approach has been questioned by researchers whereby these programs may be designed upon only half of the necessary information needed for successful translation into practice (Bolling, van Mechelen et al. 2018). This has parallels to the remote-athlete academy rugby union setting, where it could be considered that a lack of appreciation for the contextual differences of this specific cohort may be facilitating the overall scarcity of 'evidence' to support these strategies in the first place. It has therefore been suggested that researchers revisit and re-conceptualise their approaches to establishing injury surveillance and athlete monitoring practices to more comprehensively inform the following stages of the injury prevention frameworks (Bolling, van Mechelen et al. 2018). This means the contextual components of the TRIPP framework would come first then be incorporated into an overall evaluation at the end. This could therefore help establish the sustainable practices and feedback loops necessary at the beginning to facilitate the informed decision making and evaluation further along the frameworks.

In circling back to the first section of this review, a key observation was that contextual information integral to the appropriate design and evaluation of sporting innovations could be limited due to the current staged approach of most injury management models. This, together with the growing understanding of sports performance and injury as emergent outcomes from ‘complex systems’, has meant that attempts to develop and evaluate athlete monitoring and injury surveillance systems should consider multi-level, top-down, middle-out and bottom-up implementation approaches. With specific mention to self-report methods, observations by Saw, Main et al. (2015) state that the successful implementation of these methods are influenced by multi-factorial and multi-level interactions between the social environment (organisation, intra-personal, individual) and the particular methods chosen (capture mode, accessibility, time burden etc). These findings support the notion by Donaldson, Lloyd et al. (2017) that an interventions impact is a function of both the interventions quality and use. It is therefore pragmatic to source evidence-based approaches to both the specific development of sports-specific interventions and their implementation strategies that account for these factors.

Implementation science, ‘the scientific study of methods to promote the systematic uptake of research findings and other evidence-based practices’ (Bauer, Damschroder et al. 2015), is a relatively new research field in sport, but offers potential mechanisms to systematically develop and evaluate the quality and use of App-based athlete monitoring and injury surveillance systems. An implementation intervention is ‘a single method or technique to facilitate change’, while an implementation strategy is considered the ‘integrated set, bundle, or package of discreet implementation interventions selected to identify or address barriers to implementation success’ (Bauer, Damschroder et al. 2015). The crux of implementation science is it is focused upon the ‘iterative process and interactions’ that lead to successful development, evaluation and translation of scientific innovations. It is for this reason that implementation science constitutes and accounts for a lot of the core tenets of complexity theory, whereby a ‘web of determinants’ describes the multi-level ‘iterative processes and interactions’ behind particular outcomes (Braithwaite, Churruca et al. 2018). Therefore, implementation studies are generally focused on the ‘how’ and ‘why’ rather than the evidence (what) behind the intervention. Utilising sports-relevant applications of implementation science can help account for the previously established complexity of sport as well as support the evidence-based, multi-level development and implementation of App-based athlete monitoring and injury surveillance systems.

2.8.2 A Six-Step Intervention Development Process

The Six-Step Intervention Process proposed by Donaldson, Lloyd et al. (2016) represents a staged framework for the development of sport related interventions based upon both public health and implementation science propositions (Figure 16). The framework starts with gathering research evidence together with practitioner experience to ensure the intervention is based upon sound ideas and reason. Following this first step, experts within both practice and research settings relevant to the context and ideas established in the previous stage are consulted to provide feedback. This is important so that the translation of the research is deemed credible, and the intervention ideas are considered acceptable to prospective end-users. The intervention should then be developed to a point where it can be tested by end-users and against key success metrics. Finally, evaluating the intervention against a relevant theory such as the diffusion of innovations theory (Rogers 1993), together with obtaining feedback from early implementers is needed to assess how likely the intervention is to succeed as well as what necessary changes may need to be considered.

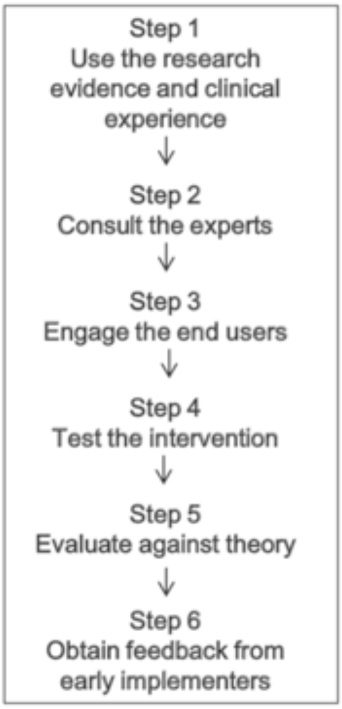


Figure 16: A Six-Step Intervention Process for Sport proposed by Donaldson, Lloyd et al. (2016)

The Six-Step Intervention Process utilises some key aspects of implementation science such as understanding the implementation context and adopting a multi-level or ecological approach to implementation activities as seen in steps 1 and 2 (Bauer, Damschroder et al. 2015). Engaging the end-users in implementation activities and testing is also a principle of implementation science apparent in steps 3 to 5 (Bauer, Damschroder et al. 2015). The application of the framework has been seen within community Australian Football (Donaldson, Lloyd et al. 2016) which shares remote-athlete commonalities with academy rugby union such as access to professional staff and common facilities. The framework was used to first establish a multidisciplinary intervention group (project steering group), then conduct two targeted literature reviews, undertake an online expert consensus process, test the program multiple times in different settings and finally obtain feedback from end-users through focus groups and survey feedback. It is conceivable a similar approach can be taken in academy rugby union settings whereby steering groups and the alignment of multi-level regional academy involvement could be initiated to support the development process.

The only criticism of the development framework is that it may overly simplify aspects and be too open to interpretation, especially when multi-level stakeholder engagement is needed. In a follow up to the original Australian Football community paper that proposed the six-step process Donaldson, Lloyd et al. (2017) incorporated aspects of Intervention Mapping, another public health-based framework that facilitates innovations development, implementation and evaluation (Bartholomew, Parcel et al. 1998). The authors specifically focused on Step 5 of the Intervention Mapping process and its application can be seen in Figure 17. The Intervention Mapping process asks more focused questions at each stage which guide stakeholders as to better understanding how to develop success metrics e.g. Task 1 asks for stakeholders to nominate the specific roles of stakeholders within the process, and Task 4 suggests stating the metrics that will describe the 'use' success metrics (reach, adoption, implementation). Incorporating such aspects and others from Intervention Mapping into Steps 2, 3 and 4 of the Six-Step Process could be worthwhile extensions that add clarity to the development process, while still allowing for the natural application of the steps within a particular context.

Intervention Mapping Step 5 Task		Purpose
Task 1	Identify potential FootyFirst adopters and implementers	To identify individuals and organisations that would be involved in, or would influence, FootyFirst adoption and implementation by community-AF coaches within the targeted league
Task 2	Establish a FootyFirst implementation planning group with representatives of potential FootyFirst adopters and implementers	To link FootyFirst developers (ie, the project team) to programme adopters/implementers (ie, coaches)
Task 3	State FootyFirst use outcomes and specify reach, adoption and implementation performance objectives	To describe what the implementation activities should accomplish including who had to do what for coaches to be reached and FootyFirst to be adopted and implemented
Task 4	Specify determinants of FootyFirst reach, adoption and implementation	To identify what will influence whether or not coaches performed the actions needed to accomplish the performance objectives.
Task 5	Identify change objectives for FootyFirst reach, adoption and implementation	To link FootyFirst reach, adoption and implementation performance objectives and determinants, to create change objectives
Task 6	Select theory-informed, evidence-based and context-specific FootyFirst reach, adoption and implementation strategies	To identify specific strategies to achieve the change objectives
Task 7	Design interventions for FootyFirst reach, adoption and implementation	To develop and produce materials and resources to operationalise the implementation strategies

Figure 17: Operationalised Intervention Mapping process used by Donaldson, Lloyd et al. (2017)

2.8.3 The RE-AIM Evaluation Framework

The RE-AIM Framework (Glasgow, Vogt et al. 1999) is a well-known implementation science tool that has previously been used in a remote-athlete setting (Ekegren, Donaldson et al. 2014). The RE-AIM Framework consists of five dimensions; reach, effectiveness/efficacy, adoption, implementation, and maintenance. These dimensions allow researchers and practitioners to describe and evaluate the 'use' and 'effectiveness' of monitoring and surveillance strategies, providing an objective assessment of key metrics such as 'adherence' and 'quality'. Given the RE-AIM Framework was initially developed for public health interventions, Finch and Donaldson (2010) proposed sports-specific recommendations for the framework, which can be used to customise around sports related objectives (Figure 18). These recommendations enable the RE-AIM Framework to answer questions relating to how many athletes the intervention reaches in total and display the number of athletes successfully utilising and benefiting from the intervention.

DIMENSION	*ORIGINAL DEFINITION*	SPORTS SETTING MATRIX DEFINITION
Reach	Proportion of the target population that participated in the intervention.	% of participants exposed to the intervention / representativeness of participants.
Effectiveness	Success rate if implemented as in guidelines.	% participants able to execute the intervention appropriately or level of agreeableness regarding quality.
Adoption	Proportion of settings, practices and plans that will adopt this intervention.	% of participants participating.
Implementation	Extent to which the intervention is implemented as intended in the real-world.	% of participants who undertake intervention as intended, or % of participants who receive promotional and support material.
Maintenance	Extent to which an intervention is sustained over time.	% of participants doing the exercises contained in the programme 3 years after being introduced to it, or % of participants intending to do the exercises contained in the programme on an ongoing basis.

Figure 18: Sports-specific adaption of the RE-AIM Framework by Finch and Donaldson (2010)

This particular framework can be used in coordination with the Six-Step Process within Step 4 (Testing the Intervention) and adds some of the Implementation Mapping principles suggested as missing from the process. This can help guide stakeholders in answering and investigating more focused and evidence-based questions as part of their development and implementation planning process. It is currently unknown whether the athlete monitoring and injury surveillance methods currently implemented within predominantly elite and professional sports settings are applicable to remote-athlete academy rugby union settings. While it is conceivable self-report methods embedded within smartphone applications can reduce a lot of the perceived barriers to large-scale longitudinal data collection in academy rugby union, the specific implementation data to inform their development and implementation strategy is also unknown. Using a combination of quantitative data from the RE-

AIM framework and qualitative semi-structured interviews, Ekegren, Donaldson et al. (2014) investigated the use of an injury surveillance system with SMS-reminders in a Australian Football community setting. The researchers found that specific information from the RE-AIM framework illustrated that, while football clubs were relatively likely to adopt the practices, specific support should be focused upon working closely with the clubs to successfully implement and maintain the practices. The qualitative investigations suggested staff were ill-equipped from an education, resource and financial incentive to successfully implement and maintain injury surveillance practices, which gave insight into why the RE-AIM results might have occurred. Furthermore, it was noted that greater flexibility in system design and input mechanisms could also improve the likelihood of success due to the understanding that not all community clubs operated in the same way and context. Accounting for such factors, and in doing so helping describe the implementation context of academy rugby union, will answer some of the above questions and has the potential to facilitate improved information and understanding of this cohort. While semi-structured interviews provide a level of evaluation detail and insight over and above online-based surveys and questionnaires, the practicality within multi-setting remote-athlete cohorts such as the English academy rugby union system is worth considering.

2.8.4 The User Mobile Application Rating Scale

In order to complete a comprehensive evaluation of the implementation context and inform the development process, user-level assessment of the intervention is needed within frameworks such as RE-AIM (Baptista, Oldenburg et al. 2017). The last step of the Six-Step Process suggests allowing for the end-users (athletes) to feedback on perceptions of intervention 'quality'. This means user-orientated evaluations are also required and integral to completing the feedback cycle. A recent systematic review into the specific evaluation of health related Apps by McKay, Cheng et al. (2018) suggested that three components should be considered when reviewing health Apps; 1) usability and functionality, 2) critique of the Apps potential to influence intended behaviour/education, and 3) the quality of the App and its content. The User Mobile App Ratings Scale (uMARS), developed by Stoyanov, Hides et al. (2015) is an evidence-based assessment tool specific to health apps. It consists of items identified from a literature search of web and App quality rating criteria and has been suggested as a simple tool that can reliably be used by end-users to assess the quality of health Apps (Stoyanov, Hides et al. 2016). The uMARS is the simplified, user version of the more detailed 'expert' MARS tool (Stoyanov, Hides et al. 2015) and comprises 31 questions, mostly using a Likert-Scale format, evaluating Apps on three key domains; 1) Objective App Quality (Engagement, Functionality, Aesthetics, Information), 2) Subjective Quality (likelihood of recommendation to others, future use, overall rating), and 3) Educational Value or Behavioural Change (impact on knowledge, attitudes, awareness, behaviour). Reliability studies show an internal consistency (alpha=0.90) and interrater reliability (alpha=0.79) (Stoyanov, Hides et al. 2016) that makes the tool the only current reliable and evidence-based option currently that specifically assesses the quality of health related Apps (Stoyanov, Hides et al. 2016, McKay, Cheng et al. 2018, Soomro, Chhaya et al. 2019).

Some researchers suggest the development of a clear conceptual definition of 'App quality' and a theoretical framework in which to test this definition would further strengthen the uMARS, however the tool has already shown great promise in providing this much needed bottom-up assessment (Baptista, Oldenburg et al. 2017). The tool has also been used to assess App-based athlete monitoring and injury surveillance systems in remote-athlete and youth settings such as cricket (Soomro, Chhaya et al. 2019). The researchers administered the uMARS survey to athletes via a web-based survey instrument which resulted in a 38% response rate (16 out of 42 athletes). This compared to the 15% response rate (12 out of 78 clubs) of the semi-structured interviews from the Ekegren, Donaldson et al. (2014) study shows the ability to capture a greater breadth of feedback. The remote-athlete status and nation-wide regional academy program make qualitative assessments such as semi-structured interviews previously used to gather feedback problematic. Given the uMARS can be sent and completed digitally it can gather a far greater breadth of information and potentially be combined with more depth-based interview techniques in smaller groups. The tool also assesses components of engagement, functionality, aesthetics, information and subjective ratings of likely behaviour/education impact, suggested as key to assessing health Apps by McKay, Cheng et al. (2018) in their review. According to the Diffusion of Innovations theory, the 'perceived' effectiveness and quality of an innovation is seen as a greater driving factor of implementation than the objective evidence surrounding the efficacy of the intervention itself (Rogers, Singhal et al. 2009). The uMARS therefore presents as a suitable tool to combine with the RE-AIM Framework and complete a comprehensive evaluation of an App-based, athlete monitoring and injury surveillance system in academy rugby union

2.8.5 *Summary of Developing and Evaluating Sporting Implementation Strategies:*

- Understanding the environment, task and person specific conditions (context) and how these interrelate help inform the development, implementation and evaluation process and should be considered the first step in sporting innovation strategy.
- The application of Implementation Science focuses upon the ‘iterative process and interactions’ that lead to successful development, evaluation and translation of scientific innovations and can be used to aid in understanding the context.
- Utilising the Six-Step Intervention Development Process and adapting this using context-driven principle of Intervention Mapping can provide a structure for approaching the development of context-driven sporting innovations.
- When evaluating the acceptability and viability of sporting innovations and their implementation strategies in the real-world it is important to consider multi-level (top-down, middle-out and bottom up) assessment methods that evaluate both the ‘use’ and ‘quality’ of an intervention.
- The RE-AIM Framework and its sporting conceptualisation, the Sports Setting Matrix can be adapted to any context and employed to define and evaluate multi-level intervention use and quality.
- Utilising domain and intervention specific tools to assess interventions such as smartphone applications is important given their unique components. The User Mobile App Ratings Scale is a valid and reliable tool that can be embedded within the RE-AIM Framework to help evaluate participant-perceived-quality metrics.

2.9 Rationale for Current Research

Sport represents one of the most popular and polarising forms of human activity and entertainment with far reaching public health benefits but also safety considerations (Foster, Shilton et al. 2018, NDP Group 2019). To improve both the performance and safety of sport participation, high-quality data is needed to inform evidence-based decision-making (Finch 2006, Bourdon, Cardinale et al. 2017). Even though important, systematic and ongoing high-quality data collection within sport is still considered rare (O'Brien and Finch 2014, Ekegren, Gabbe et al. 2016, Shaw, Orchard et al. 2017). Athlete development pathways are important to the sporting landscape as they influence both the professional and entertainment sporting product, and the general public's participation in sport (Gulbin, Croser et al. 2013). Many of these pathways can be categorised as 'remote-athlete settings' whereby capturing high-quality data from these athletes is particularly restricted due to access, resource, operational and logistical barriers (Ekegren, Donaldson et al. 2014, O'Brien and Finch 2014, Ronnby, Lundberg et al. 2018, Duignan, Slevin et al. 2019, Neupert, Cotterill et al. 2019, Soomro, Chhaya et al. 2019). England Rugby's regional academy system operates as a remote-athlete development pathway and subsequently little empirical athlete monitoring and injury surveillance data is available to inform practice (Trewartha and Stokes 2015, Till, Weakley et al. 2020). Given the global popularity of Rugby Union together with a comparatively high injury risk in relation to other team sports, this lack of evidence is concerning.

Current sports performance and injury prevention research advocates capturing data relating to 1) the contextual environment (multi-level ecological data), 2) biopsychosocial descriptors of training and competition stress-response, and 3) injury epidemiology to represent the multi-faceted nature of sport (Finch 2006, Donaldson and Finch 2013, Bourdon, Cardinale et al. 2017, Glazier 2017). In order to reflect the growing acceptance that sports performance and injury are in fact emergent outcomes from complex systems, research and development should look to embrace strategies that include whole of sport approaches that focus on pattern-recognition profiling, rather than solely isolating variables, and involve top down, middle out, and bottom up implementation and evaluation (Bekker and Clark 2016, Bittencourt, Meeuwisse et al. 2016, Glazier 2017). Utilising athlete monitoring approaches to quantifying the stressors and demands an athlete is exposed to (Load), the response to this Load (Response) and the potential negative outcomes of injury through injury surveillance together with implementation and evaluation data can support the recommendations of the available research.

A plausible solution to largescale, high-quality, yet practical remote-athlete data capture is the development of bespoke, App-based, athlete monitoring and injury surveillance systems utilising evidence-based self-report methods (van Mechelen, van Mechelen et al. 2014, Soomro, Sanders et al. 2015, Verhagen and Bolling 2015, Düking, Achtzehn et al. 2018, Lyons, OBroin et al. 2018, Duignan, Slevin et al. 2019, Soomro, Chhaya et al. 2019). Apps can be designed fit-for-purpose with self-report measures embedded, and only require the already ubiquitous use of a mobile phone. Data from self-reported methods such as Session-RPE (Athlete Load), Wellbeing and Life Stress Questionnaires (Athlete Response) and the Oslo Sports Trauma Research Centre Injury Questionnaire can be seamlessly captured, amalgamated and actioned remotely by multiple stakeholders. While the utility of App-based interventions and mobile health is promising, research into the development and implementation of these systems within sporting contexts is limited representing an opportunity for innovation (van Mechelen, van Mechelen et al. 2014, Duignan, Slevin et al. 2019). It has been proposed research evidence alone is insufficient to develop implementable sports innovations such as App-based athlete monitoring and injury surveillance systems (Donaldson, Lloyd et al. 2016). The application of Implementation Science which focuses upon the 'iterative process and interactions' that lead to successful development, evaluation and translation of scientific innovations may therefore be useful in future-focused research designs.

This research will therefore utilise key implementation science principles and frameworks together with the aforementioned athlete monitoring and injury surveillance best-practices to outline the process of developing, evaluating and innovating an App-based solution to reducing the barriers to remote-athlete data capture in English academy rugby union. In doing so, this research will be the first to outline the development of an App-based athlete monitoring and injury surveillance system using the Six-Step Intervention Development Process (Donaldson, Lloyd et al. 2016) and employ both the RE-AIM Framework (Finch and Donaldson 2010) and uMARS (Baptista, Oldenburg et al. 2017) assessment tools to systematically evaluate both the intervention and implementation strategy. In completing this research, findings may be used to help address the current rarity of ongoing, high-quality data collection in sport, increase the availability of empirical evidence within the English academy rugby union system and other remote-athlete pathways, and provide much needed insight into the development, implementation and evaluation of App-based innovations in sport.

3 CHAPTER THREE

Exploring the Development and Implementation Process of a Bespoke Smartphone Application for Athlete Monitoring and Injury Surveillance in Academy Rugby Union

3.1 Introduction

The management of traditional paper and manually inputted digital collection modes poses a major barrier to large, remote-athlete monitoring and injury surveillance, and in turn, the ability to positively influence performance and safety. Compounding this is the distinct lack of applied research documenting how to address these barriers utilising modern technologies and systematic design and implementation principles (Burgess 2017, Gabbett, Nassis et al. 2017). The development of bespoke athlete monitoring and long-term surveillance solutions utilising modern technologies is of particular relevance to England Rugby's regional academy system, whereby the sport's comparably high injury-risk, together with a lack of injury research within its large, predominantly remote-athlete talent pathway means this cohort could be considered particularly vulnerable (Hendricks, Till et al. 2019, Till, Weakley et al. 2020).

Athlete self-report measures consist of a combination of short reflections and/or multiple-choice questions that capture information on the sporting environment, activities and people themselves (Gallagher, Needleman et al. 2017, Saw, Kellmann et al. 2017). The ability to monitor both sport and non-sport related loads, responses and outcomes mean athlete self-report measures not only provide an attractive option for many levels of sport but are also heavily represented within studies assessing load-response-injury interactions (Jones, Griffiths et al. 2017). Given athlete self-report measures are now being marketed as short, custom-designed tools for daily completion, their specific utility in remote-athlete settings within digitised and mobile-app based solutions is becoming increasingly favoured by practitioners and researchers (van Mechelen, van Mechelen et al. 2014, Soomro, Sanders et al. 2015, Sadeghi and Alizadeh 2017, Düking, Achtzehn et al. 2018, Hamlin, Wilkes et al. 2019, Soomro, Chhaya et al. 2019).

Emerging technologies such as that of mobile health (mHealth) have been suggested as having the potential to revolutionise sports medicine (van Mechelen, van Mechelen et al. 2014, Verhagen and Bolling 2015). This technology uses mobile phone-based computers called 'smartphones and their inbuilt programs called 'applications' (Apps) to capture and amalgamate data remotely. The use of smartphone 'Apps' for remote-athlete monitoring and injury surveillance purposes has previously been investigated (Verhagen and Bolling 2015, Düking, Achtzehn et al. 2018), and has already been used in other remote-athlete settings such as cricket, distance running and Gaelic Sports (Sadeghi and Alizadeh 2017, Lyons, OBroin et al. 2018, Ronnby, Lundberg et al. 2018, Soomro, Chhaya et al. 2019). There are, however, several implementation and sustained-usage challenges that have been suggested as stemming from a lack of multi-level understanding and alignment (Ronnby, Lundberg et al. 2018, Duignan, Slevin et al. 2019).

While the bespoke design of App-based self-report methods shows promise in solving the time, management and system related challenges to traditional monitoring and injury surveillance in remote-athlete cohorts, little research exists detailing the systematic development and implementation of these innovations in sporting settings (Verhagen and Bolling 2015). There are however examples of this being done within sports injury prevention research. The Six-Step Intervention Development Process proposed by (Donaldson, Lloyd et al. 2016) outlines a generalisable process researchers and practitioners can use to develop implementable sporting interventions and innovations. Table 3This development process is built upon established implementation science and intervention mapping principles, and has been used previously to inform the development of injury prevention strategies in community Australian Football (Donaldson, Lloyd et al. 2016), youth handball (Ageberg, Bunke et al. 2020) and schools Rugby Union (Hislop, Stokes et al. 2017). Two complementary ideas underpin the development process; 1) 'evidence-based practice' results from the integration of scientific discovery, practitioner expertise and end-user values (Braithwaite, Churruca et al. 2018), and 2) research evidence alone is insufficient to develop implementable interventions (Hanson, Allegrante et al. 2014). These ideas are focused around engaging the full-spectrum of stakeholders (researchers, expert practitioners and end-users) and promoting context-driven solutions that are more likely to be widely adopted, and deliver innovations impact (Donaldson, Lloyd et al. 2017). This study seeks to employ these best-practice implementation science principles to address the lack of literature surrounding the development and implementation processes of App-based sporting interventions. It is hoped this will lead to a reduction in barriers to remote-athlete data collection and management, resulting in improved English academy rugby union performance and safety outcomes.

Study Aims

I. Outline the development process of a bespoke athlete monitoring and injury surveillance smartphone application for English academy rugby union.

II. Present the outcomes of the development process and detail a proposed implementation strategy.

3.2 Methods

To systematically approach the design and documentation of the App-based sporting intervention and associated implementation strategy, the Six-Step Intervention Development Process proposed by Donaldson, Lloyd et al. (2016) was used as a framework. In this context, the App, and its associated implementation strategy were the 'intervention' that was developed through the guiding framework proposed by the Six-Step Intervention Development Process. The development of the App and its associated implementation strategy is aimed at helping solve a problem within the English Academy Rugby Union setting, and its ability to do so will be evaluated, in a similar way that a new medical drug or exercise program intervention would be. The evaluation of the implementation strategy as part of the overall intervention is an important aspect of implementation science. The six steps were as follows; Step 1: a review of research evidence and clinical experience, Step 2: a consultation with the experts, Step 3: the engagement of end-users, Step 4: the design and testing of the intervention and implementation strategy, Step 5: the evaluation against theory, and Step 6: obtaining end-user feedback. This study employed the first four steps, whereby steps one, two and three answer the studies first aim, and step four answers the second aim. An outline of the study design can be seen in (Table 3). The last two steps of the Six-Step Process are addressed in Chapter Four of this thesis.

Table 3: Six-Step Development Process proposed by (Donaldson, Lloyd et al. 2016) used to develop an athlete monitoring and injury surveillance smartphone application in English academy rugby union

Six-Step Development Process		**Study Application**
Step 1	Research Evidence and Clinical Experience	⇒ Contextual Foundations Report ⇒ Literature Review
Step 2	Consulting Experts	⇒ Academy Education Forums ⇒ Project Steering Group ⇒ Prototype Proposal and Development
Step 3	Engaging End-Users	⇒ Prototype Testing in Real-World Setting ⇒ Multi-level qualitative and quantitative feedback
Step 4	Design and Testing of the Intervention and Implementation Strategy	⇒ Smartphone Application Development ⇒ Proposed implementation Strategy

(Hanson, Allegrante et al. 2014, Donaldson, Lloyd et al. 2016, Donaldson, Lloyd et al. 2017, Hislop, Stokes et al. 2017, Braithwaite, Churruca et al. 2018, Ageberg, Bunke et al. 2020). Two scientific methods underpinned the study design; 1) a literature search to identify published research evidence incorporating the terms “sports performance”, “sports safety” “athlete-monitoring”, “injury surveillance”, “implementation science”, “rugby union”, “athlete talent pathways” “athlete development pathways”, and 2) the capturing of clinical and practitioner expertise and end-user feedback via document analyses, focus groups and formal feedback meeting minutes and reports, facilitated through workshops, conferences and interest groups. Detailed depictions of these scientific methods and their applications within each of the four steps mentioned were dynamically integrated within the results section. This was purposefully done to best illustrate the iterative interaction between methods and results within modern implementation science research, allowing for a more dynamic representation of real-world application. This study involved multi-level stakeholders representing research, governing bodies and leagues, applied practitioners (managers, coaches, sports science and medicine), athletes and industry technology providers. Again, their detailed involvement is depicted within the results section in order to best capture their real-world involvement. A favourable ethical opinion was given by the Research Ethics Approval Committee for Health (REACH) at the University of Bath (EP 16/17-276) and informed consent from participants, and parents (for those under 18 years at time of the study) compliant with the 2018 General Data Protection Regulation (GDPR) was obtained (see Appendices: Player Consent Example) prior to data collection.

3.3 Results

3.3.1 Contextual Foundations and Literature Review

This first step in the development process was initiated to maximise the likelihood that strategy and decision-making is informed by the current evidence base and implementation context (Donaldson, Lloyd et al. 2016). The first two chapters of this thesis provide an in-depth review of both the research context and available literature used to inform this research approach. The findings of these chapters showed an inability to capture high-quality data and information insights within the English regional academy rugby union system was limiting evidence-based decision-making surrounding the performance, safety and wellbeing of these athletes. Given the associated injury-risk with rugby union (Viviers, Viljoen et al. 2018), the current ongoing surveillance being done at other levels of English rugby (Cross, Williams et al. 2018) and the foundational influence emerging athletes in a popular sport such as rugby union have up and down the sporting talent pathway (Gulbin, Croser et al. 2013), a clear rationale for research existed (Bergeron, Mountjoy et al. 2015, Trewartha and Stokes 2015, Phibbs, Jones et al. 2018, Hendricks, Till et al. 2019, Till, Weakley et al. 2020). The multi-faceted and multi-level stressors and stakeholders outlined in Table 4 conceivably experienced by academy rugby union athletes, together with a remote-athlete status, make this a particularly challenging and vulnerable cohort and context to manage. The subsequent literature review and recommendations for developing, implementing and evaluating strategies to reduce the barriers to remote-athlete data capture are outlined in Table 5. These recommendations provided the basis of initial decision-making and discussion leading into the following steps of the development process.

Table 4: Summary of Research Context into English Academy Rugby Union

	Individual Characteristics	Interpersonal Relationships	Organisational Structures/Stressors	
Academy Athletes	⇒ Male 14-18 years. ⇒ Remote-athletes. ⇒ Key period of growth and maturation. ⇒ Limited high-quality data and information to inform decision-making.	⇒ Parents. ⇒ Social Networks. ⇒ Multiple school/sport teachers and coaches. ⇒ Academy coaches, sports science and medicine, management, recruitment. ⇒ England National age-grade team and staff. ⇒ Club and County rugby staff ⇒ Other sport staff ⇒ Career and Commercial Agents.	⇒ School and academic requirements. ⇒ Social/family requirements. ⇒ Lifestyle requirements e.g. nutrition, sleep, casual work. ⇒ Multi-level rugby and other sport training and competition. ⇒ Complimentary training e.g. gym, mental.	(Malisoux, Frisch et al. 2013, Palmer-Green, Stokes et al. 2013, Rith-Najarian, McLaughlin et al. 2014, Palmer-Green, Stokes et al. 2015, Phibbs, Jones et al. 2018, Hendricks, Till et al. 2019, Till, Weakley et al. 2020)
Academy System	⇒ 14-regional Academies. ⇒ Periodic access to centralised facilities through aligned professional clubs. ⇒ Academy specific off-site regional centre operations. ⇒ Academy specific staffing covering qualified management, coaching, sports science and medicine. ⇒ Varying levels of access to players.	⇒ Academy athletes and parents. ⇒ Multiple school stakeholders. ⇒ Professional club senior team management, coaches and sports science and medicine staff. ⇒ England National age-grade management and staff. ⇒ Rugby Football Union (RFU) management. ⇒ University researchers and expert collaborators. ⇒ Counties, Club and community rugby staff.	⇒ Professional Club and England National Team Talent identification, verification, development and transition objectives. ⇒ Long-term athlete development, safety and wellbeing. ⇒ RFU and Premiership Rugby Audit requirements (budgets, staffing, operations, best practice). ⇒ Professional Club requirements (budgets, staffing, operations).	(Palmer-Green, Stokes et al. 2015, McCarthy, Collins et al. 2016, Barden 2018, Phibbs, Jones et al. 2018, RFU 2018, Hendricks, Till et al. 2019, Till, Weakley et al. 2020)
External Stakeholders	⇒ Parents with different socio-economic and cultural backgrounds. ⇒ Peers and other family members. ⇒ Schools (independent, private, religious, state/college). ⇒ County, Club and Community rugby. ⇒ National Teams and Governing Bodies.	⇒ Academy athletes. ⇒ Regional Academy staff.	⇒ Long-term athlete development, safety and wellbeing view-points. ⇒ Potentially varying temporal performance requirements e.g. club vs school vs academy vs national team. ⇒ Varying socio-economic and cultural requirements. ⇒ Varying facilities and scheduling requirements.	(Ar and Polman 2007, Mellalieu, Neil et al. 2009, Rith-Najarian, McLaughlin et al. 2014, Hendricks, Till et al. 2019, Till, Weakley et al. 2020)

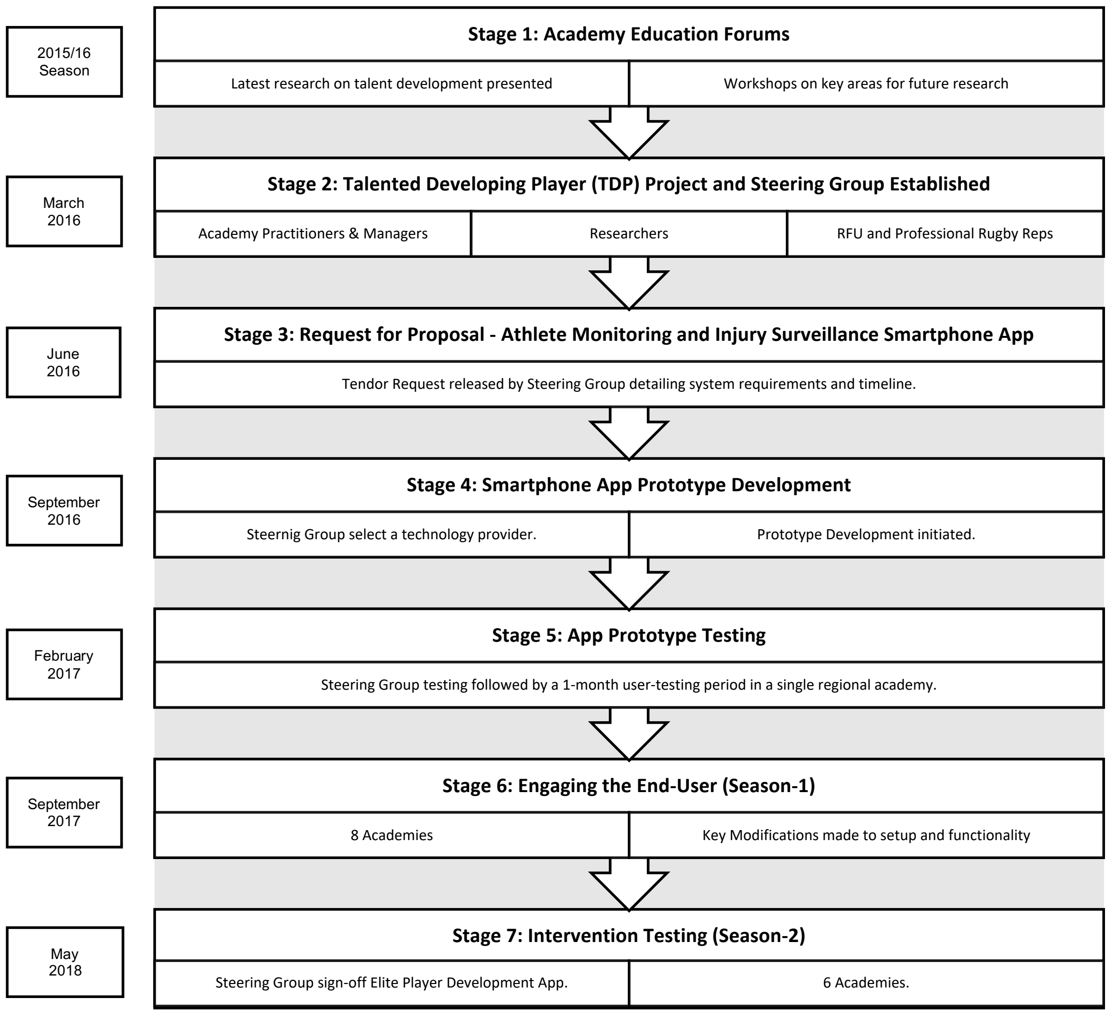
Table 5: Summary of Literature Review into Remote-Athlete Monitoring and Injury Surveillance

	Definition and Terminology	Remote-Athlete Methods and Quantification	Scientific Underpinning and Rationale	
Athlete Load Monitoring	⇒ 'Load' refers to 'The total stressors and demands applied to the players, comprising both rugby-related and non-rugby-related inputs, of which the components can be characterised according to their frequency, intensity, duration and type. ⇒ Represents the 'exposure' variables and the first stage of data capture.	⇒ Session Rate of Perceived Exertion (session-RPE). ⇒ The product of a load event/situation's (session) 'intensity' and duration. ⇒ Can be quantified as a single global load measure in arbitrary units (AU) or broken in constituent parts to describe Load frequency, intensity, volume/time and type/mode.	⇒ 'Load' is a recognised scientific construct and is operationalised within the specific rugby union literature. ⇒ Load is a key component of the stress-response cycle and considered a quantifiable and modifiable injury risk-factor. ⇒ Session-RPE display appropriate ecological, construct and user validity and reliability for remote-athlete academy rugby. ⇒ Session-RPE can be embedded within digitised forms, used to remotely describe both rugby and non-rugby related loads.	(Phibbs, Roe et al. 2017, Quarrie, Raftery et al. 2017, West, Williams et al. 2019)
Athlete Response Monitoring	⇒ Describes the individual athlete biopsychosocial stress-response to load. ⇒ Represents the 'response' variables and the second stage of data capture.	⇒ Perceptual Wellbeing and Life Stress questionnaires. ⇒ Bespoke and individualised inventories using Likert-type scales and descriptors.	⇒ The stress-response cycle is central to psychosocial models of injury aetiology. ⇒ Bespoke wellbeing questionnaires combined with life stress elements can detail a large variety of biopsychosocial responses and are sensitive to changes in load. ⇒ Can be embedded within digitised forms and self-reported for remote-athlete use.	(McLean, Coutts et al. 2010, Saw, Kellmann et al. 2017, Noon, James et al. 2018, Britton, Kavanagh et al. 2019)
Injury Surveillance	⇒ The ongoing, systematic collection of injury data. ⇒ Describes the occurrence of and factors associated with injury. ⇒ Represents a negative 'outcome measure' of the sporting environment and third and final stage of data capture. ⇒ *Acute 24-hour time-loss injuries;* an injury that results in a player being unable to participate in rugby training or matches for more than 24-hours post injury event. ⇒ *Overuse injuries:* injuries without a specific, identifiable event responsible for their occurrence of which may not initially result in time-loss but are considered as restricting performance.	⇒ Self-reported acute time-loss injuries that can be validated by medical professionals. ⇒ Self-reported overuse injuries collected via the Oslo Sports Trauma Research Centre (OSTRC) injury questionnaire. ⇒ Injuries classified using a modified Orchard Sports Injury Coding System (OSICS). ⇒ Measures of severity (cost) and incidence (rates) are used to describe the injury problem.	⇒ Supported by the rugby union injury surveillance consensus statement. ⇒ OSTRC injury questionnaire considered a valid and reliable injury self-report tool tested in a remote-athlete setting. ⇒ Utilising both acute time-loss and overuse methods considered the most appropriate for youth athletes and rugby union cohorts. ⇒ Self-reported injury methods can be embedded within digitalised forms for remote-athlete use.	(Fuller, Molloy et al. 2007, Clarsen, Myklebust et al. 2013, Clarsen, Ronsen et al. 2014, Cross, Williams et al. 2018)
Smartphone Application Technology	⇒ Smartphones are mobile phone-based computers. ⇒ Applications (Apps) are the in-built programs within smartphones that can capture and amalgamate data remotely.	⇒ Bespoke Apps on athletes' smartphones can be used to input athlete monitoring and injury surveillance data remotely. ⇒ Session-RPE, Wellbeing, Life Stress and Injury forms can be embedded and quantified within these Apps then sent directly to the appropriate Academy and external stakeholders.	⇒ Mobile Health (mHealth) considered a key component in revolutionising medicine. ⇒ Ability to cost-effectively, non-invasively and practically capture, amalgamate and quantify large datasets from remote-athletes. ⇒ Ability to design bespoke Apps to fit contextual needs and provide both specific visualisation and raw data export. ⇒ Being successfully utilised in several remote-athlete monitoring and injury surveillance settings.	(van Mechelen, van Mechelen et al. 2014, Verhagen and Bolling 2015, Sadeghi and Alizadeh 2017, Düking, Achtzehn et al. 2018, Ronnby, Lundberg et al. 2018, Duignan, Slevin et al. 2019, Soomro, Chhaya et al. 2019)

3.3.2 Consulting with Experts

This second step ensured the research and contextual evidence compiled within the previous step is specific to the sport, aligned with current applied best-practice, and can be translated into practical project solutions and objectives (Donaldson, Lloyd et al. 2016). It was therefore important that information from step 1 be discussed and synthesised through several channels, as engagement of multidisciplinary key stakeholders (e.g. prospective deliverers, users, researchers and governing bodies) is shown to have a positive effect on the development and implementation process and outcomes (Fixsen, Blase et al. 2009, Donaldson, Lloyd et al. 2017, Tee, Bekker et al. 2018). A blended, staged approach was therefore initiated that includes both step 2 and 3 of the Six-Step Intervention Development Process whereby the full-spectrum of stakeholders were engaged (Table 6).

Table 6: A blended, staged approach to steps 2 and 3 of the Six Step Development Process



With reference to Stage 1 in Table 6, during the 2015/16 academy season, the RFU held regional academy workshops and a national conference. The aim of these education forums was to provide an opportunity for the research within step 1 to be presented and discussed by key stakeholders. The forums and conference were attended by academy managers, their support staff and associated schools, RFU national and regional academy staff, and academic researchers. The directive from these forums was that more needed to be done to investigate and inform the youth and academy pathways and re-affirmed many of the contextual challenges and gaps in the literature previously presented.

Stage 2 was therefore initiated whereby a project and expert steering group was set up to action the directives from stage 1. The Talented Developing Player (TDP) Project was an RFU commissioned project set up to investigate the interactions between athlete performance, safety and successful transition into professional rugby from the regional academy system. The steering group was made up of selected representatives from the RFU, researchers, academy staff and the professional game of rugby in England (Premiership Rugby Ltd; PRL). These representatives included subject matter experts in athlete monitoring and injury surveillance from academic settings, key RFU and PRL pathways management staff, and selected regional academy club management, sports science and medicine practitioners. The TDP Steering group were therefore tasked with formalising key project objectives, managing their implementation, and acting as a filter of information between users, applied practitioners and that of high-level decision makers at the RFU and PRL. The first key objectives of the TDP Project looked to address three core aspects: 1) the regional academy implementation context, 2) the training, playing, life habits and stressors of academy players and its link with injury, and 3) the physical characteristics of academy players across the age-groups. In order to address core aspects 1 and 2, athlete monitoring and injury surveillance plans were initiated using the information gained from step 1 and under the direction of the steering group.

The previous research recommendations combined with investigations throughout the education forums by the RFU had found that there was considerable desire to see athlete monitoring and injury surveillance data captured via an App. This resulted in the RFU, in partnership with an external technology provider, to begin developing a bespoke App to be used as a remote-athlete monitoring and injury surveillance system (Stages 3 and 4 in Table 6). Input surrounding the selection of the external technology provider and initial specifications for the App development was supported by key research staff and members of the TDP steering group.

After a period of development, the external technology provider presented an App prototype based on the specifications provided by the steering group. This prototype was presented first internally to key members with minor modifications suggested, then tested by the steering group and signed off as fit for purpose and further end-user testing. It was agreed a single academy, by whom one of the members of the steering group was employed, would complete a 1-month ‘soft-pilot’ to test the scalability of the application before completing a full-scale user-testing protocol. This was to ensure that familiarisation strategies to educate, setup and register regional academies, staff and athletes would be as relevant and specific as possible.

3.3.3 Engaging the End-User

Following the soft-pilot, a full-scale pilot (season-1) was initiated with eight out of the total fourteen regional academies representing an approximate 60% of the academy landscape. The academy involved in the soft-pilot was not involved in the season-1 pilot meaning a total of nine academies (~65%) had utilised the App. The academies were recruited through consultation with the RFU national academy manager whereby they specifically selected regional academies and personally approached their staff. Throughout this first full-scale pilot period, members of the steering group compiled and discussed feedback from the participating academies and their athletes relating to the barriers they faced in successfully utilising the App. This information was collected via regular phone and electronic correspondence, face-to-face academy visits, steering group meetings, and app usage metrics generated from the internal App exports function (athlete registrations, status responses and questionnaire completion rates) and Google Analytics (App service disruption, connectivity, total logins and survey completion/usage time) (© 2020 Google) (see Appendices Example Feedback Channels). The feedback was compiled and actioned in real-time throughout the season-1 pilot and categorised into three sections relating to 1) the Individual or User, 2) the academies and academy landscape – Organisational or Environmental, and 3) System or Technology and can be seen in Table 7.

Table 7: End-user barriers and modifications made to the athlete monitoring and injury surveillance App throughout the season-1 Pilot.

Category	Barriers	Feedback identified through	Solution
Individual/ User (n=4)	Low number of athletes receiving SMS reminders due to forgetting to input their own mobile details.	App Usage Reports	Added mobile number to consent form so player does not need to add it as part of registration.
	Inability of academy practitioners to process and analyse data.	Athlete and Practitioner Correspondence and Steering Group discussion	Developed a bespoke athlete monitoring excel template that uses App exports to process and analyse individual data.
	Annoying to have to type in password every time you log in.	Athlete and Practitioner Correspondence	Added password remember function to App.
	Lack of time to remind athletes to complete surveys.	Practitioner Correspondence	Developed an SMS reminders function for the players.
Organisational/ Environmental (n=3)	Highly variable levels of adherence across season-1 pilot period.	App Usage Reports	Work more closely with Academies, set benchmarks for adherence and provide weekly report.
	Lack of understanding and application surrounding the use of athlete data.	Practitioner Correspondence and Steering Group discussion	Proposed agenda item at Regional Academy Manager meetings and focus group set up with key industry stakeholders to align application and key messages.
	Gradual decrease of adherence throughout pilot.	App Usage Reports	Provide weekly reports to Academies on adherence and athlete data.
System/ Technology (n=6)	Inability to determine between a 'missed data point' and 'planned rest-day' in App data export.	Steering Group discussions	Added 'rest day' option to the activity menu in App and both 'rest day' and 'no activity-injured' categories to export.
	Inability to export large athlete data files from App in a single export e.g. more than 2-months at a time.	Researcher pilot testing	Raised with the App company who developed a fix that allows 12-months of data to be exported in a single export.
	Slow processing speeds with increasing athlete activity on the App.	Athlete and Practitioner Correspondence and Steering Group discussion	Raised with the App company who developed a more efficient data indexing code that improved functionality.
	Inability to internally group message/communicate with athletes within the Application.	Practitioner Correspondence	Outside of budgetary scope.
	Lack of internal App analytics, visualisation and sharing together with a lack of uniformity among practitioners and academies on what these should be.	Athlete and Practitioner Correspondence	Outside of budgetary scope. Developed a bespoke athlete monitoring excel template that practitioners could use with App exports to better analyse, visualise and share data. Provided support in developing in-house academy solutions to compliment the App based around specific academy/practitioner needs.
	Inability to view athlete adherence and current report status within the App without having to download export each time, making adherence and squad management difficult.	Practitioner Correspondence	An improved adherence functionality was added to App that showed coloured icons indicating current adherence level and fitness status next to athlete names.

3.3.4 Design and Testing of the Intervention and Implementation Strategy

This step of the development process both outlines the App design, and the strategy used to implement and ultimately test the smartphone App intervention in a real-world setting. Utilising the contextual information gathered from previous steps is fundamental to assessing whether our synthesis and proposed solutions are effective. An overview of the results from this step can be seen in

Table 8. Final modifications were made to the App, and the formal implementation procedures and evaluation measures were developed. A total of six out of the fourteen regional academies participated in the season-2 Pilot (43%), however, of those six, two were academies not previously involved, meaning the total academies involved across the two seasons was ten (71%).

This section of chapter three addresses the second aim of this explorative study by presenting the intervention developed (App), and the survey workflows created, based on the findings and modifications from the season-1 pilot. The results from the Evaluation Outcomes section of Table 8 are addressed in chapter four of this thesis as previously stated.

Table 8: The intervention developed, and the implementation and evaluation strategy proposed resulting from Steps 1-3 of the Six-Step Development Process

COHORT

English Regional Academy System (Staff members and athletes)

INTERVENTION

Athlete Monitoring and Injury Surveillance System

↓

Elite Player Development (EPD) App

↓

Daily Participant Survey Flow
- Current Status
- Injury Status
- Perceptual Wellbeing
- Activity Status

↓

Weekly Participant Survey Flow
- Life Stress
- Performance Restriction

↓

Survey Data Visualisation and Export Capabilities
- Adherence Rates
- Academy-Level in-App Analysis
- Raw Data Export (Player-Level Analysis)

PROPOSED IMPLEMENTATION STRATEGY

Recruitment
- Practitioner Workshop
- Study Briefing Document
- Academy Tutorial
- Participation Sign-Off

↓

Setup
- Consent
- Registration
- Player Workshop

↓

Academy Feedback Reports & Templates
- Weekly Report
- Athlete Monitoring and Injury Surveillance Excel Template

EVALUATION OUTCOMES

Chapter Four will aim to outline and address the metrics and results of the intervention and implementation strategy.

3.3.4.1 *Intervention – Elite Player Development App*

The Elite Player Development (EPD) App was developed to remotely capture, then centrally aggregate athlete monitoring and injury surveillance data for export and use by practitioners and researchers. The product was designed in collaboration with the Rugby Football Union and MyLife Digital Ltd, UK. The navigation through the App involves four daily, and two weekly survey flows that are detailed in Figure 19. An example of the App home page can be seen in Figure 20. A description of the EPD App surveys is provided in the following sections and a User Guide (see Appendices EPD App Registration and User Guides). Players provided mobile phone numbers and were sent short message service (SMS) reminders for their daily surveys at 1100-hours and weekly surveys at 1500-hours on a Monday.

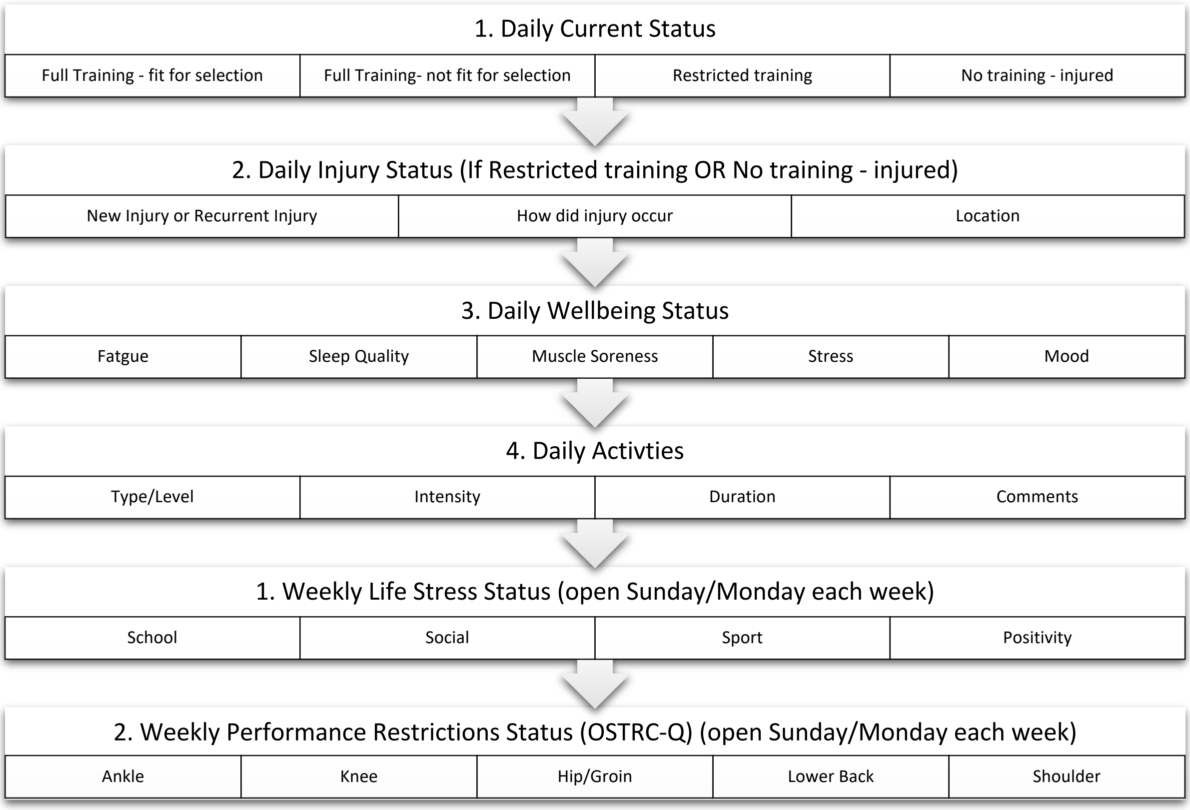


Figure 19: Elite Player Development (EPD) App User Flow

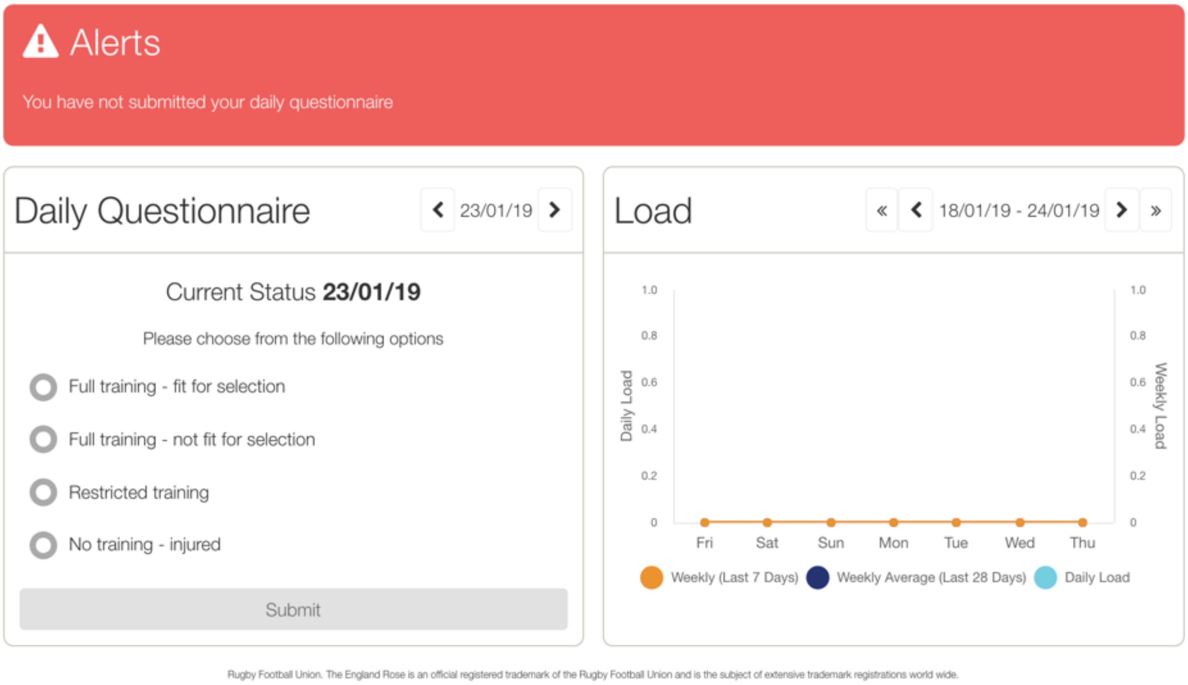


Figure 20: Elite Player Development (EPD) App home page

Daily Current Status

The current status survey flow was designed as part of the injury status (i.e. to determine the severity of injuries) and for academy squad management purposes. Players could select from four options; the two 'Full training' options were to determine training or match availability based on non-injury related factors (e.g. fitness levels, holiday, other social/academic engagements) while 'Restricted' and 'No training' referred directly to injury.

Daily Injury Status

The daily injury status survey was designed in accordance with the rugby union injury definitions and collection consensus by Fuller, Molloy et al. (2007), using an athlete self-report, 24-hour time-loss definition across. Injuries were self-reported across three levels: 1) New Injury or Recurrent Injury, 2) Injury Setting (Rugby Training, Rugby Match, Other Activity), 3) Location (Head-Concussion, Head-Non-concussion, Upper Limb, Trunk, Lower Limb).

Daily Wellbeing Status

The daily wellbeing status survey was designed using the survey proposed by McLean, Coutts et al. (2010) (Figure 21). This survey describes an athletes subjective, acute, physical and psychological responses to their environment and is considered a common and ecologically useful method in many elite sports settings (Gastin, Meyer et al. 2013, Saw, Main et al. 2016). The scores from each category can be summed individually (1 represents no problems and 5 substantial problems), or as an overall wellbeing total (5 represents no wellbeing problems and 25 substantial wellbeing problems).

	1	2	3	4	5
FATIGUE	Very fresh	Fresh	Normal	More tired than normal	Always tired
SLEEP QUALITY	Very restful	Good	Difficulty falling asleep	Restless sleep	Insomnia
GENERAL MUSCLE SORENESS	Feeling great	Feeling good	Normal	Increase in soreness/tightness	Very sore
STRESS LEVELS	Very relaxed	Relaxed	Normal	Feeling stressed	Highly stressed
MOOD	Very positive mood	A generally good mood	Less interested in others &/or activities than usual	Snappiness at team-mates, family and co-workers	Highly annoyed/ irritable/down

Figure 21: Subjective Wellbeing Questionnaire developed by McLean, Coutts et al. (2010)

Daily Activities Status

The daily activities status survey was designed using the Session-RPE Load method proposed by Foster, Florhaug et al. (2001). Session-RPE Load has been shown to be a simple, valid and reliable means in which to capture the frequency, intensity, time, type and overall acute, biopsychosocial response to physical activity in this population (Phibbs, Roe et al. 2017). The Session-RPE Load method and the steps taken by players through the EPD App are shown in (Figures 22-24). Athletes recorded 1) the activity type, 2) the perceived intensity rating based on 'verbal anchors', and 3) the total duration of activity participation in minutes alongside any further comments. This information was then used to determine Session-RPE Load in arbitrary units (AU) (rate of perceived exertion multiplied by duration in minutes). Load was displayed as a daily total, 7-day weekly total, and 7-day weekly average over a 28-day period.

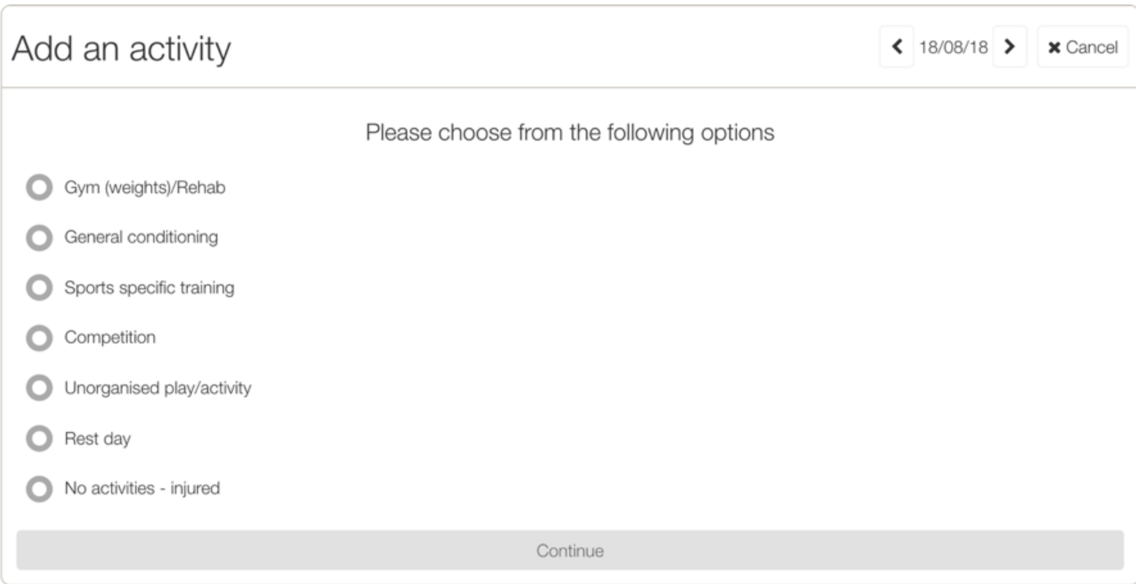


Figure 22: Session-RPE Load Survey – 1) Activity Type

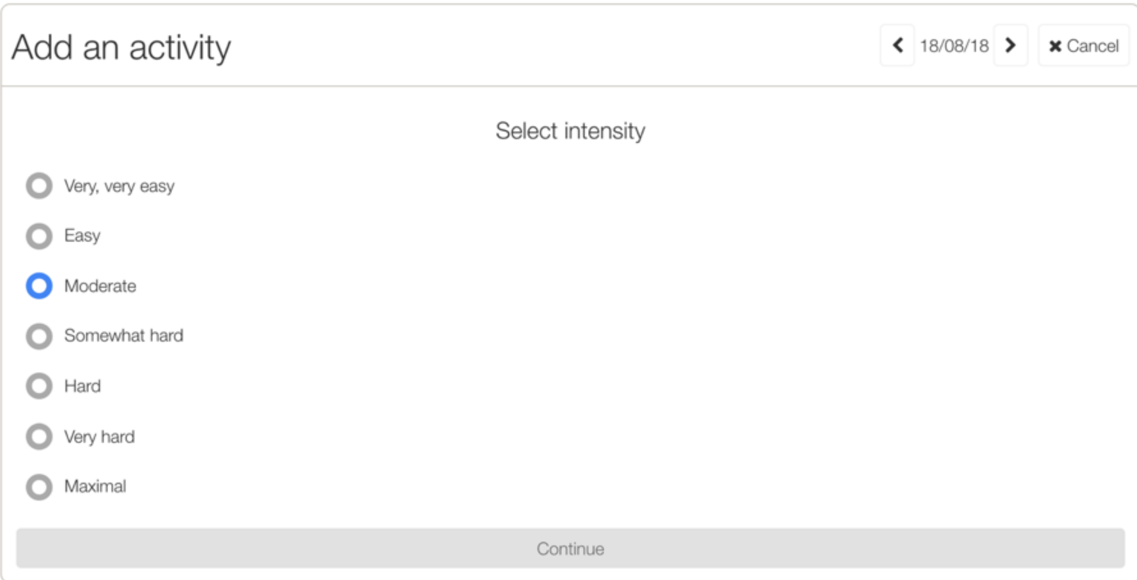


Figure 23: Session-RPE Load Survey – 2) Rate of Perceived Exertion intensity rating

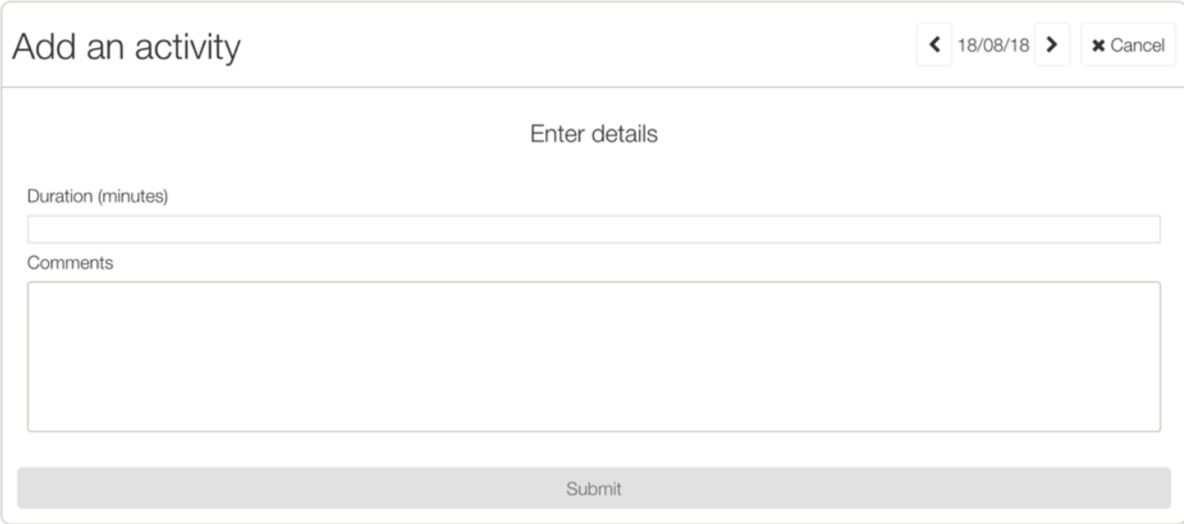


Figure 24: Session-RPE Load Survey – 3) Activity duration and comments

Weekly Life Stress Status

The weekly life stress status survey was designed using adapted questions from both the Recovery Stress Questionnaire for Athletes (RESTQ-Sport) (Villanueva, Bennett et al. 2010) and the Daily Analysis of Life Demands for Athletes (DALDA) (Rushall 1990). Questions from the RESTQ-Sport and DALDA that had related specifically to managing with academic study, relationships, general sports performance and positivity levels were identified as these were deemed pertinent to the academy rugby union environment and been previously correlated with injury risk (Jones, Griffiths et al. 2017). The 'Life Stress' survey questions were constructed to provide details as to an academy athlete's affective levels of managing/coping with elements of life stress relating to their 1) School, 2) Friends and Family, 3) Sport(s). The fourth question relates to 'positivity' and gives a sense of how the first three questions are impacting affective elements of overall psychological wellbeing. This survey was open to athletes to complete from Sunday 0001-hours until Monday 2400-hours.

	1) I have managed well at school	2) I have managed well with my friends and family this week	3) I have managed well with my sport(s) this week	4) Overall, I have been feeling positive this week
None of the time				
Rarely				
Some of the time				
Often				
All of the time				
Total				

Figure 25: Life Stress Survey

<u>*Weekly Performance Restrictions (PRQ) Status*</u>

The weekly performance restrictions status questionnaire was designed using the validated Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire (Clarsen, Myklebust et al. 2013). Overuse injuries are defined as; *'injuries without a specific, identifiable event responsible for their occurrence of which may not initially result in time-loss but are considered as restricting performance'* (Clarsen, Myklebust et al. 2013). The questionnaire name was changed to the 'Performance Restriction Questionnaire' (PRQ) to better align with player and practitioner understanding. Players reported on issues to five body regions: 1) shoulder 2) back, 3) hip and groin, 4) knee and 5) ankle. For each region of the body four questions were posed. These questions can be seen in (Figure 26) which presents an example of these for the knee region. The PRQ was integrated into the EPD app in order to capture injuries that did not present as time-loss using the Fitness and Injury Status daily surveys to potentially give a greater context to injury in this setting. This questionnaire was open to players to complete from Sunday 0001-hours until Monday 2400-hours.

Part 1: Knee Problems

Please answer all questions regardless of whether or not you have problems with your knees. Select the alternative that is most appropriate for you, and in the case that you are unsure, try to give an answer as best you can anyway.

The term "knee problems" refers to pain, ache, stiffness, swelling, instability/giving way, locking or other complaints related to one or both knees.

Question 1

Have you had any difficulties participating in normal training and competition due to knee problems during the past week?

☐ Full participation without knee problems

☐ Full participation, but with knee problems

☐ Reduced participation due to knee problems

☐ Cannot participate due to knee problems

Question 2

To what extent have you reduced you training volume due to knee problems during the past week?

☐ No reduction

☐ To a minor extent

☐ To a moderate extent

☐ To a major extent

☐ Cannot participate at all

Question 3

To what extent have knee problems affected your performance during the past week?

☐ No effect

☐ To a minor extent

☐ To a moderate extent

☐ To a major extent

☐ Cannot participate at all

Question 4

To what extent have you experienced knee pain related to your sport during the past week?

☐ No pain

☐ Mild pain

☐ Moderate pain

☐ Severe pain

Figure 26: Performance Restriction Questionnaire (Example for the Knee) (Clarsen, Myklebust et al. 2013)

Survey Data Visualisation and Export Capabilities

The EPD App was designed as a remote-athlete data capture intervention, with mechanisms to monitor squad availability, wellbeing and total load exposure through the Daily Summary and Load analysis visualisations in (Figure 27) and individual athlete adherence and player status (Figure 28). All raw data from each survey and adherence metric could be exported for bespoke analysis (staff only access). Simple academy-level analysis of totals was also provided for each survey within the EPD App when selecting the survey from the home-screen menu. Players had access to their own individual player load graph such as can be seen in Figure 27 and a personal activity log (Figure 29) via their individual accounts.

Figure 27: Squad Availability and Academy-Level analysis visualisation from the EPD App

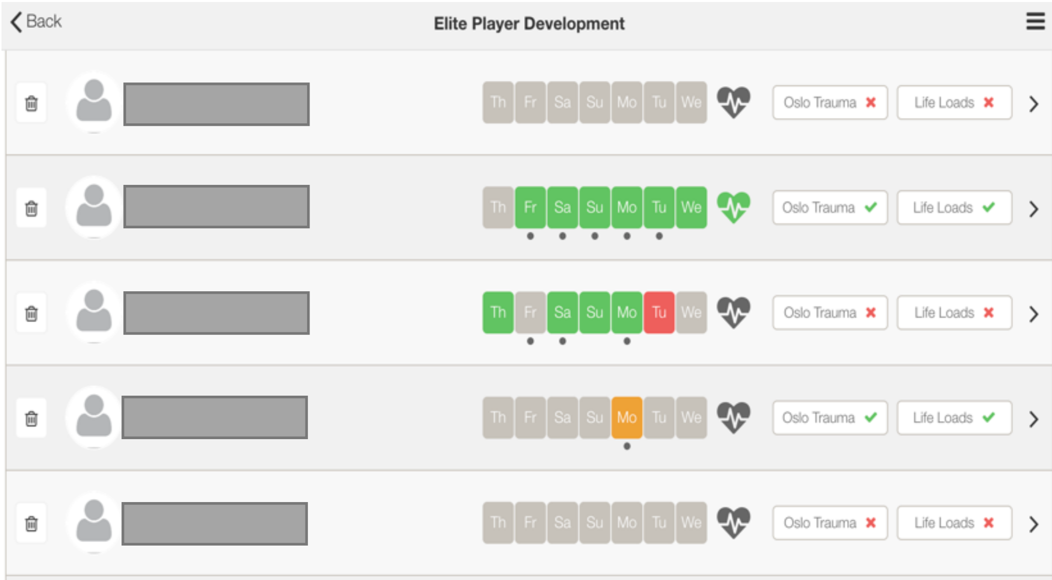


Figure 28: Individual athlete adherence and analysis visualisation from EPD App

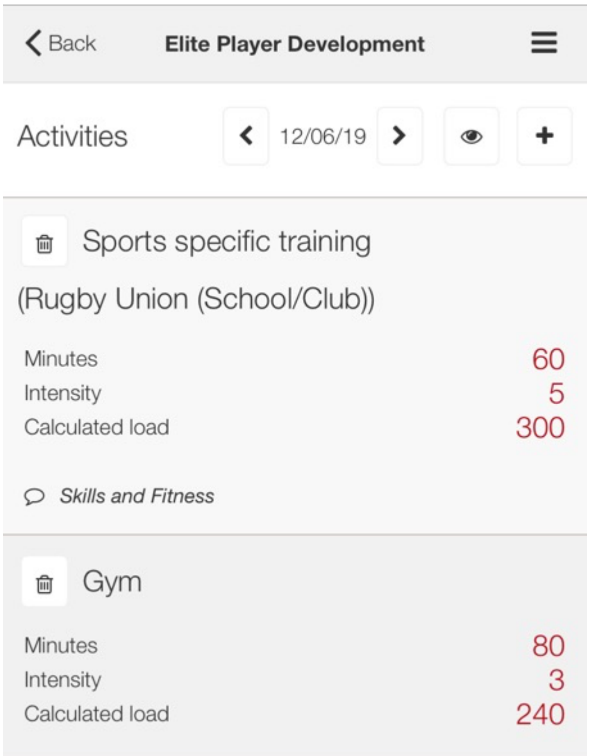


Figure 29: Individual Player Activities Log from the EPD App

3.3.4.2 Proposed Implementation Strategy

Recruitment

The recruitment process would be split across four phases aiming to best engage and brief academies before they decided to participate. This enabled academies to assess the perceived feasibility of the study requirements within their setting and make an informed, multidisciplinary decision on participation.

1. Academy Practitioner Workshop: Academy strength and conditioning, sports science and medicine staff were presented to on the TDP Project and EPD App and asked to complete a short survey registering interest and further questions (see Appendices Academy Practitioner Workshop Survey).
2. Academy Briefing Document: Using information from the workshop, and summarising the work completed throughout the previous seasons Education Forums, App Development and Pilot phases, an Academy Briefing Document was created. This document was sent to each regional academy manager and lead strength and conditioning/sports science practitioner and aimed to a) introduce the TDP Project and it's first objectives, b) describe the background and rationale, then c) explicitly detail the requirements and benefits for academies if they chose to participate (see Appendices Academy Briefing Document).
3. Academy Tutorial: After discussing the Briefing document internally, academies had the opportunity to schedule a one-on-one tutorial of the EPD App and discuss any questions regarding the study and requirements.
4. Academy Briefing Document Sign-Off: In order to engage the multi-level and interdisciplinary stakeholders needed to complete a comprehensive due diligence cycle, academies were finally asked to provide sign-off of the academy briefing document from a representative of senior management, academy management and nominate a lead staff member who would be responsible for the day-to-day operations and communications with researchers.

Setup

Once regional academies had completed the recruitment and sign-off, a three-phase setup process would be initiated to on-board academy players to the EPD App and educate them on the use and importance of the surveys.

1. Consent: Academies were sent links to both a parental, and player specific online, informed consent form (Online Surveys Copyright © 2019, Jisc). The links were password-protected with all data stored behind a GDPR compliant firewall which was expressed within the consent form. Once academies received these, they then emailed these links to the appropriate players and parents. Both player and parental (for those under 18) informed consent forms were completed before the registration process could be initiated (see Appendices Player Consent Example).
2. Registration: Academies were asked to provide both staff account details (staff name, email and role) and playing group account details (age, performance, regional groups e.g. U16, Elite or schools, north/west etc). Once players completed the consent process, they were added to specific groups in the EPD App and sent an invitation email asking them to verify their account, followed by a second email confirming their account and asking to set a new password. Once a password was set, players were taken to an internet browser login screen where they logged in using their email and password. They were then instructed to download the smartphone application (Elite Player Development App – MyLife Digital Ltd, UK) from their smartphone's App Store (See Appendices EPD App Registration and User Guides).
3. Player Workshops: Once players had successfully registered and logged into the EPD App a player workshop was booked with each academy. The workshops were designed to introduce players to athlete-monitoring and injury surveillance, the importance and application of the information they were providing and then walk players through the daily and weekly survey flows. The themes used to translate these aspects were a) What it takes to succeed in an academy setting and beyond (discussion-based), b) The EPD App as a High-Performance Diary, c) What players personally, their academy coaches and the RFU can do with the information, and d) How this can be used in your day-to-day routines. Academy staff were also provided with short video tutorials on all aspects of the EPD App and an education focused,

‘Using my Load Graph’ video to give players some individual interaction with the App (see Appendices Academy and Player Education Workshops).

Weekly Reports, Monitoring and Surveillance Template

As part of the ongoing support service to the participating academies, and as a way to improve engagement, a weekly report and bespoke athlete-monitoring and injury surveillance excel template were provided. The weekly report was anonymised, academy specific (their own data only) and emailed to the nominated lead academy practitioner and academy manager each Monday before 1100-hours (Figure 30). The report was constructed based on feedback from academies and the RFU surrounding what were the simplest yet most important metrics to monitor weekly. The report included engagement and adherence metrics (total players, number of players completing 5 out 7 daily surveys, and number of players completing 7 out of 7 daily surveys), and athlete-monitoring metrics (individual player weekly minutes, total season minutes, weekly competition fixtures, and total season competition fixtures). The competition fixtures were further broken down into the different sports that players had accrued competition fixtures from. A ‘key points’ section was also included to quickly summarise the graphs. The athlete-monitoring and injury surveillance excel template was created specifically to analyse and visualise the EPD App raw export data. Each academy was sent a template along with instructions and video tutorial. Academies were also given one-on-one tuition on the template and ideas on how to adapt and modify the existing template to fit the metrics, workflows and presentation needs of their program.

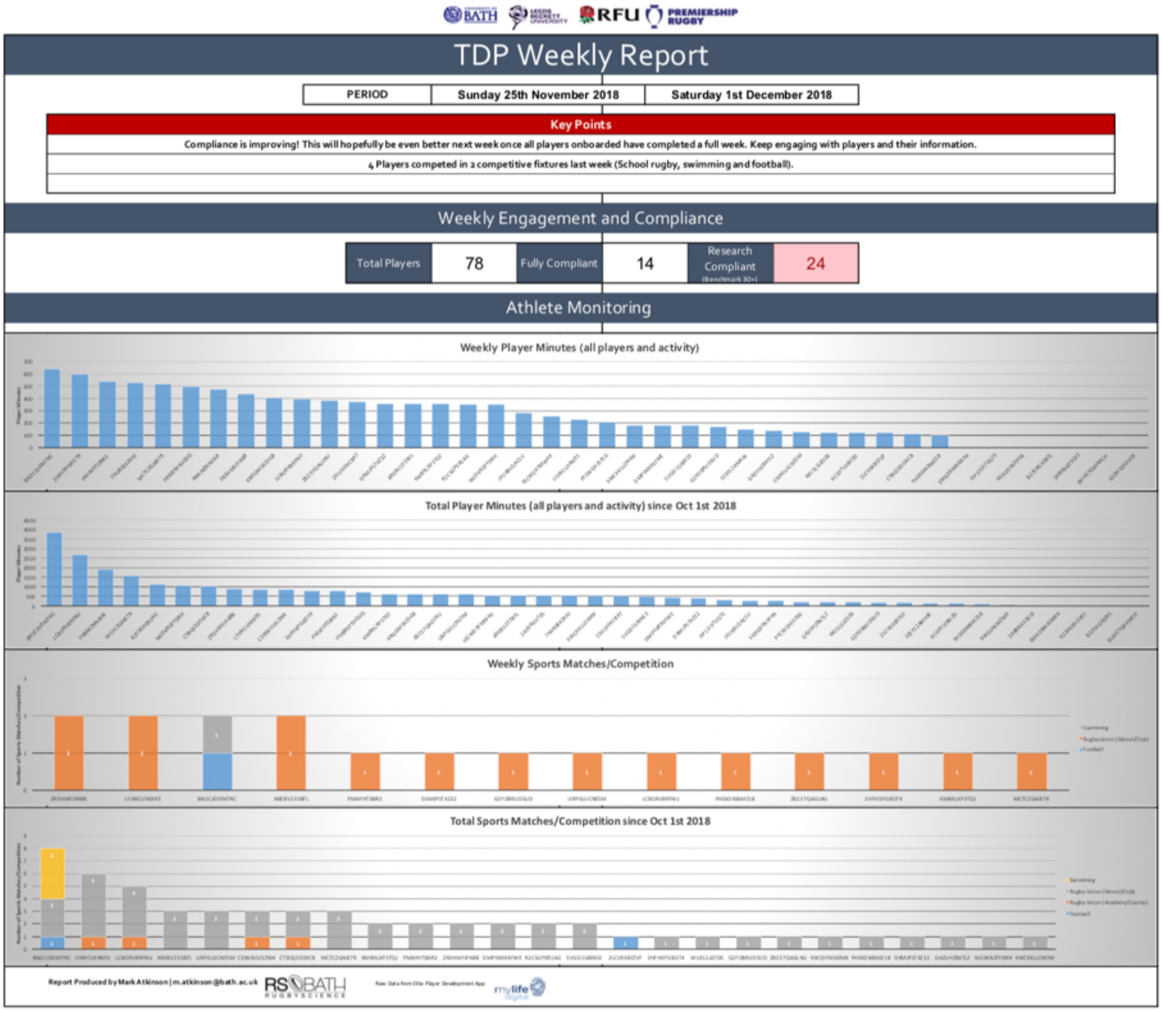


Figure 30: Weekly academy report

3.4 Discussion

Innovations development and successful implementation is considered a complex, iterative process that requires evidence, experience and the ability to align these to contextual factors (Rogers, Singhal et al. 2009, Donaldson, Lloyd et al. 2016, Braithwaite, Churruca et al. 2018). To capture these considerations, this study sought to utilise the Six-Step Intervention Development Process proposed by Donaldson, Lloyd et al. (2016) to outline the development and implementation strategy of an App-based athlete monitoring and injury surveillance innovation. This innovation was developed to facilitate performance and safety improvements in English academy rugby union through enabling the ongoing capture of remote-athlete data, a well-known barrier currently preventing the attainment of much needed longitudinal evidence in this cohort (Trewartha and Stokes 2015, Phibbs, Jones et al. 2018, Hendricks, Till et al. 2019, Till, Weakley et al. 2020). The study's findings depict the design of the Elite Player Development (EPD) App and its associated implementation strategy using the first four steps of Six-Step Development Process. The findings help inform both future innovations development, and provide a platform for further longitudinal, real-world evaluation studies that can lead to innovations impact.

The Six-Step Development Process was originally conceived with a focus on developing implementable injury prevention programs. Studies within community Australian Football (Donaldson, Lloyd et al. 2016), youth handball (Ageberg, Bunke et al. 2020) and school rugby union (Hislop, Stokes et al. 2017) have employed the Six-Step process to successfully develop their injury prevention programs and implementation strategies. The 'generalisable' nature of the Six-Step Development Process however means the steps can be applied to other sporting innovations such as the development of the EPD App in the current study. To date, the current study seems to be the first to apply this systematic, evidence-based approach to comprehensively outline the development and implementation strategy of an App-based athlete monitoring and injury surveillance system.

Step one of the process detailed the foundations on which the EPD App was designed using both contextual reporting to understand the scope of the problem and a literature review to gain clarity on evidence-based approaches. The key findings showed an inability to capture high-quality data and information insights within the English regional academy rugby union system was limiting evidence-based decision-making. The remote-athlete status of regional academy players and the diversity of regional academy settings and stakeholders meant that solutions needed to focus on the ability to amalgamate data from a large user-base remotely, using tools that were easily accessible, scalable and adaptable but also evidence-based. These findings were confirmed by both the published literature (Till, Weakley et al. 2020) and then cross-checked by clinical and practitioner experts in step two which resulted in a collaborative decision to develop an App-based athlete monitoring and injury surveillance prototype (EPD App). Using a combination of evidence-based literature, contextual investigation and then validating this against multi-level clinical and practitioner expertise and opinion is considered highly effective in planning successful interventions (Fixsen, Blase et al. 2009).

Whilst the use of digital, mobile and App-based technologies to capture athlete monitoring and injury surveillance data has become more prevalent in sport (Ekegren, Gabbe et al. 2014, Soomro, Sanders et al. 2015, Fagher, Jacobsson et al. 2017, Møller, Wedderkopp et al. 2017, Sadeghi and Alizadeh 2017, Düking, Achtzehn et al. 2018, Lyons, OBroin et al. 2018, Phibbs, Jones et al. 2018, Ronnby, Lundberg et al. 2018, Raihana, Radin et al. 2019, Holmes, Sherman et al. 2020) previous studies have yet to systematically detail the complex, iterative process, associated with developing and implementing these innovations. The previous studies with an athlete monitoring and injury surveillance focus have instead described basic workflows and implementation procedures as is standard for most methods sections, (Ekegren, Gabbe et al. 2014, Møller, Wedderkopp et al. 2017, Phibbs, Jones et al. 2018), or combinations of user feedback, technical development overviews, and pilot testing timelines (Fagher, Jacobsson et al. 2017, Sadeghi and Alizadeh 2017, Düking, Achtzehn et al. 2018, Lyons, OBroin et al. 2018, Ronnby, Lundberg et al. 2018, Raihana, Radin et al. 2019, Soomro, Chhaya et al. 2019, Holmes, Sherman et al. 2020). While this information is useful, it lacks the contextual detail and multi-faceted approach to clearly inform and progress both the scientific, and real-world understanding as to ‘what makes a successful intervention’ and ‘how can successful translation of knowledge to practice be replicated’. These are key principles of implementation science (Donaldson and Finch 2013, Bauer, Damschroder et al. 2015, Braithwaite, Churruca et al. 2018), and their absence from previous research may be the reason these studies report issues surrounding ongoing use, practitioner/end-user understanding, and the practicality of the data captured outside of a research context. A key take home message from this study was that the documentation and specific description of how processes interrelate and blend in the real-world matters. The reality is this can paint a messy picture that may potentially be left out of most research attempting to fit the traditional scientific structure. What is evident within this study's structure is that methods and results are not clearly separated, which must be noted, could cause consternation from a purely academic perspective. What this illustrates however is that by attempting to constrain research writing within such tight bounds, we may in fact inhibit the articulation of certain critical contextual elements. This lack of articulation then may lead to the very issues reported in previous studies when trying to implement research in real-world settings. These findings challenge the traditional notion of trying to fit a pre-conceived scientific structure and approach to real-world implementation problems. This study provides an outlook on study design and format, whereby greater focus is placed on documenting the iterative nature and real-world application through the integration of methods and results. This approach could lead to greater research translation and impact. This will hopefully provide both the necessary contextual detail for future decision-making, leading to the improved implementation and innovations impact of the EPD App.

Following steps one and two, step three of the development process, involved the proposed prototype being exposed to end-user feedback. This was to maintain the iterative nature of the development cycle and begin the process to a practically applied solution. While step two involved general information and idea validation through educational forums and the establishment of a multi-level project steering group to initially scope and guide development, the addition of end-user feedback helps further target real-world application. This was why steps two and three were somewhat blended in the current study to combine the subset of experts, who would already understand the literature, context and subsequent EPD App, with that of lesser experienced end-users (athletes and practitioners). An interesting observation regarding the end-user feedback was that it generally followed a theme of firstly, System/ Technology based issues, then Organisational/ Environmental and lastly Individual/ User. This suggested the end-user may first attribute the technology/intervention itself as a barrier, then move to suggestions the environment the intervention is placed in was limiting application, and them finally consider their own individual understanding, preferences and values may also be impacting success. This type of processing has parallels within behavioural psychology research whereby 'attribution theory' and the 'self-serving biases' suggest that when individuals are presented with a barrier or problem, they will first externalise issues before gradually looking inwards to how their own perceptions and abilities may be influencing outcomes (Taylor and Doria 1981). If, however, individuals are presented with a successful outcome, and asked to attribute the factors underlying this success, people will then do the opposite and internalise outwards. These processes also seem to be further enhanced within team/group settings making this particularly relevant to team sport settings such as academy rugby union. This has interesting implications for designing feedback inventories and how to effectively introduce innovations, whereby if looking to address barriers or problems, starting the reflective or educational process from an internal perspective may yield more effective results. Another major finding from the end-user feedback was there was a lack of overall, uniformity, alignment and consensus on how best to use and action the data captured from the App, a notion supported by investigations into athlete monitoring practices specifically within the professional game of rugby in England (West, Williams et al. 2019) and, generally within other team and individual sports settings (Ronnby, Lundberg et al. 2018, Duignan, Slevin et al. 2019, Raihana, Radin et al. 2019, Holmes, Sherman et al. 2020). The highly variable levels of adherence across academies and certain time-points noted in the results and the gradual decrease in adherence levels after initial positive engagement throughout the pilot speaks to a potential lack of systematic practice and accountability that can stem from alignment and consensus issues. This lack of alignment and consensus may manifest through a range of mechanisms. Organisational aspects such as high staff turnover, low job security, and insufficient long-term planning and leadership may augment efforts to align and develop consensus, Individual education and communication aspects and the gap between new and old generation thinking may also be of consideration. Furthermore, this lack of alignment and consensus could also be inherently mirroring both a potential lack of overall accountability and accepted standardisation within athlete monitoring and injury surveillance research and governance, whereby a consensus is therefore harder to establish and regulate. This presents a major foundational barrier which has previously been noted within the athlete monitoring implementation literature meaning efforts should be made to address this early on (Saw, Main et al. 2015c, Duignan, Slevin et al. 2019). Emphasising a clear vision, strategy and feedback channel is recommended as a starting point to establish alignment and consensus. Most importantly, these must be both agreed upon on multiple levels to create accountability, and then appropriately facilitated through the necessary education, support and incentivisation mechanisms to be effective.

Step four of the process focused upon achieving the second aim of this study, whereby a description of the EPD App would be presented alongside the contextually driven implementation strategy. The EPD App was designed to meet both the remote accessibility, scale and practical requirements, as well as the diverse sporting and academic contexts and specific loads experienced by regional academy rugby union athletes (Till, Weakley et al. 2020). The EPD App therefore enabled the capture of multi-sport training and competition as well as 'other' activities that did not specifically match a sport, while also allowing for note taking to provide greater detail or extra context to reporting. Ratings of academic and social/relationships stressors and coping, alongside overuse injuries and levels of performance restriction were also included in line with the evidence from step one. The academic and social/relationships inventory named 'Life Stress' was adapted from several established questionnaires to meet the requirements of the context by the project steering group. While issues surrounding construct and criterion validity as well as reliability could rightly be raised, the collective decision was made that the established questionnaires lacked ecological and face validity given their longer completion times and terminology therefore meaning they would ultimately not be taken up by academy practitioners and athletes. This made the established questionnaires not fit for purpose in the academy setting. It was therefore decided that the basic insight afforded from the adapted Life Stress inventory could be used to direct future efforts, and this was better than no insight at all. A different decision regarding the alignment with existing research versus the practicalities of the academy context was however made for the capture of activity exposure and injury data. This data was considered central to the aims of the academy setting and more likely to be engaged with even with stricter standardisation measures in place. Thus, to maximise the reliability and ensure that this data did not underestimate results, both the activity exposure and injury data was captured daily, and strictly aligned with current reliability and validity standards from previous literature (Phibbs, Roe et al. 2017, Cross, Williams et al. 2018). The practical drawback of the daily reporting approach in the academy setting is that unlike professional settings, where this information is generally collected by staff members, the academy athletes themselves would be self-reporting. This places the reporting burden on academy athletes, which may result in potential analysis complications relating to a greater likelihood of missed data points. To equate for the this, athletes were sent reminders each day and also allowed to add/delete data 2-days after reporting was initially due. This was hoped to also allow sufficient time for practitioners to follow-up with non-compliant players. Both the Life Stress, and activity exposure and injury data are examples of how a collective, multi-level understanding and decision can be reached.

From an implementation perspective, addressing the end-user feedback from step three and previous athlete monitoring and injury surveillance system adoption and usage issues was paramount. Previous studies across other sports have mentioned a lack of practitioner and athlete appreciation for the initial, and ongoing requirements of establishing and gaining value from athlete monitoring as potentially a key barrier to address (Ekegren, Donaldson et al. 2014, Ciara M. Duignan, Patrick J. Slevin et al. 2019, Neupert, Cotterill et al. 2019). This, together with the previously noted lack of alignment, consensus and faciliatory mechanisms for athlete monitoring and injury surveillance within the English rugby academy system, was hoped to be remedied through the implementation strategy. Firstly, a multi-level project sign-off process that engaged key stakeholders was initiated that was hoped to deliver clarity and alignment surrounding the intervention provide an avenue for any last stage pilot testing. This was a novel approach compared to previous studies implementing the Six-Step Development Process, (Donaldson, Lloyd et al. 2016, Hislop, Stokes et al. 2017, Ageberg, Bunke et al. 2020). While seemingly a positive addition, given the fast-paced, changing landscape of professional sports it could be still considered only a first step towards true alignment. This sign-off process was followed by a phased setup and education process that aimed to make sure both practitioners and athletes were well-informed and address previous studies concerns. Lastly, to help manage adherence and the effective use of the data within micro and macro planning and decision-making, templates and ongoing support was set up. The systematic and context-driven approach and outlining of implementation components means that both the EPD App can be comprehensively evaluated and ultimately improved throughout the proceeding development process steps for a higher likelihood intervention impact.

3.5 Conclusion

Documenting the steps to developing interventions can be useful when evaluating the overall implementation strategy. This process promotes transparency in how researchers and stakeholders collaborate during the intervention development phase and then provides a more systematic basis in which all parties can evaluate, iterate and improve. This chapter has outlined the processes taken to develop an evidence-based, context-driven solution to remote-athlete monitoring and injury surveillance in academy rugby union. Following key components of the Six-Step Intervention Development Process, such as reviewing the existing literature and context, and blending expert opinion with end-user feedback it has been possible to deliver a bespoke smartphone application that utilises current best-practices to capture the fundamental data needed to inform athlete safety, wellbeing and performance decision-making within academy rugby union. Within this process, there were instances when scientific rigour was placed foremost, while others where context-specific practicality was prefaced. Further to this, much needed research has been contributed towards outlining the development and implementation processes required to deliver App-based sporting innovations for future research. These include a multi-level sign-off, education and supporting infrastructure that engages all stakeholders and completes the feedback loop. Developing multi-level, context-driven and efficacious sporting innovations and implementation strategies however do not always guarantee success, and that is why mapping out the process and delivering top-down, middle-out and bottom-up evaluation are important to reducing the innovation-implementation gap.

4 CHAPTER FOUR

Evaluating the Development and Implementation of a Bespoke Self-Report Athlete Monitoring and Injury Surveillance Smartphone Application in Academy Rugby Union

4.1 Introduction

Emerging technologies are increasingly providing opportunities to innovate performance and safety practices in sport. Technology domains such as Mobile Health (mHealth), which involve the use of smartphones and their inbuilt computing software called Applications (Apps), can afford promising benefits to the largescale, ongoing capture and management of athlete monitoring and injury surveillance data (van Mechelen, van Mechelen et al. 2014, Verhagen and Bolling 2015). While this technology can provide adaptable, cost-effective solutions to many of the barriers facing even the most challenging cohorts such as remote-athlete development pathways, strategies to implement these innovations within sporting populations is still unclear and largely sub-optimal (van Mechelen, van Mechelen et al. 2014, Verhagen and Bolling 2015, Vriend, Coehoorn et al. 2015, Ronnby, Lundberg et al. 2018, Duignan, Slevin et al. 2019, Soomro, Chhaya et al. 2019). This means many efficacious and beneficial solutions facilitated through mHealth and App-based technology are not being realised and practically applied. The previous chapters of this thesis have identified and developed an evidence-based and contextually driven App-based solution and strategy to reducing barriers to remote-athlete monitoring and injury surveillance in academy rugby union. A key component of the Six-Step Development Process that has guided this potential solution is the testing of interventions within real-world settings, whereby ecological implementation data is reported to evaluate and systematically facilitate the eventual diffusion of innovations into applied settings (Donaldson, Lloyd et al. 2016). As stated previously, in this context, the App, and its associated implementation strategy were the ‘intervention’ that was developed through the guiding framework proposed by the Six-Step Intervention Development Process.

Published recommendations state that the successful implementation of embedded self-report methods such as those found in App-based athlete monitoring and injury surveillance systems are influenced by multi-factorial and multi-level interactions between the social environment (organisation, intra-personal, individual) and the particular methods chosen (capture mode, accessibility, time burden) (Saw, Main et al. 2015). These findings support the notion that an intervention's impact is a function of both its 'use' and 'quality' and, therefore, the ecological data to evaluate implementations should reflect this (Donaldson, Lloyd et al. 2017). Implementation science, 'the scientific study of methods to promote the systematic uptake of research findings and other evidence-based practices' (Bauer, Damschroder et al. 2015), is a relatively new research field in sport, and offers mechanisms to define and evaluate the use and quality of interventions such as App-based athlete monitoring and injury surveillance systems.

The RE-AIM Framework (Glasgow, Vogt et al. 1999) is an established implementation science tool that has previously been used in a remote-athlete setting (Ekegren, Donaldson et al. 2014). It consists of five dimensions; Reach, Effectiveness/Efficacy, Adoption, Implementation, and Maintenance. These dimensions allow researchers and practitioners to describe and evaluate the acceptability of monitoring and surveillance systems, providing an assessment of key metrics relating to intervention adherence and quality. Given the RE-AIM Framework was initially developed for public health interventions, Finch and Donaldson (2010) proposed sports-specific recommendations, which can be used to customise the RE-AIM Framework for sporting objectives. According to the Diffusion of Innovations theory, the 'perceived' quality and effectiveness of an intervention is a greater driver of implementation than the research evidence itself (efficacy) (Rogers, Singhal et al. 2009). Combining perceived, intervention-specific evaluation tools into the Effectiveness dimension is therefore warranted. The User Mobile App Ratings Scale (uMARS), developed by Stoyanov, Hides et al. (2015) is an evidence-based assessment tool specific to health apps and can therefore provide valid and reliable end-user quality assessment. It consists of items identified from a literature search of web, and App quality rating criteria and has been suggested as a simple tool that can reliably be used by end-users to assess the quality of health Apps (Stoyanov, Hides et al. 2016). The tool has also been used to assess App-based athlete monitoring and injury surveillance systems in remote-athlete settings such as cricket (Soomro, Chhaya et al. 2019). User-orientated evaluations help describe the specific design and practical usage factors behind the evaluation to complete a more comprehensive feedback loop. Given the uMARS tool assesses components of engagement, functionality, aesthetics, and perceived impact on behaviour and education, it presents as a suitable tool to combine with the RE-AIM Framework and complete a comprehensive evaluation of an App-based sporting innovation (McKay, Cheng et al. 2018). This study therefore seeks to support the comprehensive implementation strategy instigated in the previous chapters of this thesis by providing context-driven ecological data to both inform future development and implementation strategies, address the current research limitations in this area and provide more targeted future research directions.

4.1.1 Study Aims:

I. Report on context-driven measures of player ‘Reach’, ‘Effectiveness’ ‘Adoption’, ‘Implementation’ and ‘Maintenance’ to evaluate the player-usage and perceived-quality of a self-report athlete monitoring and injury surveillance smartphone application.

II. Report on academy rugby union players’ ‘engagement’, ‘functionality’, ‘aesthetics’ and ‘educational value’ ratings of a self-report, athlete monitoring and injury surveillance smartphone application.

4.2 Methods

4.2.1 Design

A two-season observational, prospective cohort study was employed, and a description of the study design can be seen in Table 9. Season-1 ran from September 1st, 2017 – May 31st, 2018 (9-months) and Season-2 from June 1st, 2018 – May 31st, 2019 (12-months). The Elite Player Development (EPD) App survey workflows and implementation procedures from the previous chapters are now combined with the evaluation procedures outlined in this experimental chapter's methods.

Table 9: Study Design

COHORT			
English Regional Academy System (Staff members and athletes)			
INTERVENTION			
Athlete Monitoring and Injury Surveillance System			
Elite Player Development (EPD) App			
Daily Participant Survey Flow			
Current Status	Injury Status	Perceptual Wellbeing	Activity Status
Weekly Participant Survey Flow			
Life Stress	Performance Restriction		
Survey Data Visualisation and Export Capabilities			
Adherence Rates	Academy-Level in-App Analysis	Raw Data Export (Player-Level Analysis)	
IMPLEMENTATION PROCEDURES			
Recruitment			
Practitioner Workshop	Study Briefing Document	Academy Tutorial	Participation Sign-Off
Setup			
Consent	Registration	Player Workshop	
Academy Feedback Reports & Templates			
Weekly Report	Athlete Monitoring and Injury Surveillance Excel Template		
EVALUATION			
RE-AIM Framework	***uMARS***		
Reach Effectiveness* (uMARS) Adoption Implementation Maintenance	Engagement Functionality Aesthetics Subjective Ratings Educational Value		
Analysis	**Analysis**		
Descriptive	**Descriptive**		

4.2.2 Cohort

English rugby union regional academy staff (sports science, strength and conditioning, physiotherapy and management) and athletes were recruited for this study. Staff members were defined as 'data-managers' (managing the adherence, and practical use of data as part of their job roles) and were educated to at least an undergraduate and/or professional coaching accreditation level. Athletes or players were defined as 'system-users' (inputting self-report information into the EPD App), were between the ages of 14 and 18-years, and from a combination of English public, private and institute schools across the designated academy regions. A favourable ethical opinion was given by the Research Ethics Approval Committee for Health (REACH) at the University of Bath (EP 16/17-276) and informed consent from participants, and parents (for those under 18 years at time of the study) compliant with the 2018 General Data Protection Regulation (GDPR) was obtained (see Appendices: Player Consent Example) prior to data collection. An important note was that not all players had the same overall exposure periods to the EPD App. While a majority of players were on-boarded at the beginning of each season, some players were added and deleted from the EPD App at various time-points throughout the study period. This was representative of the fluid and dynamic nature of athlete development pathways.

4.2.3 Intervention

The Elite Player Development (EPD) App was used to remotely capture, then centrally amalgamate athlete monitoring and injury surveillance data for export and use by practitioners and researchers. The product was designed in collaboration with the Rugby Football Union and MyLife Digital Ltd, UK. The navigation through the App involves four daily, and two weekly, survey flows that are detailed in Chapter Three of this thesis. Players were asked to use the EPD App daily throughout the study period with their raw usage data amalgamated within the App and then exported by researchers for analysis. Players provided mobile phone numbers and were sent short message service (SMS) reminders for their daily surveys at 1100-hours, and at 1500-hours on a Monday for their weekly surveys if no survey had been completed.

4.2.4 Implementation Procedures

The implementation procedures started with a recruitment process which was split across four phases. The four phases included 1) an academy practitioner workshop to discuss the EPD App and project, 2) an academy briefing document formally explaining everything discussed at the workshop, 3) an EPD App tutorial to take academies through using the EPD App, and 4) an academy briefing document sign-off from multi-level stakeholders at the club to consolidate knowledge and engagement. This process enabled academies to assess the perceived feasibility of the study requirements within their setting and make an informed, multidisciplinary decision on participation. Once regional academies had completed the recruitment and sign-off, a three-phase setup process was initiated to on-board academy players to the EPD App and educate them on the use and importance of the surveys. This included 1) a consent phase whereby password protected links to online consent forms were sent to each academy, 2) a registration phase where academy account details were set up, and 3) a player workshop phase whereby once players had consented and registered for the EPD App, they completed a workshop on how to log in, use and problem-solve. The process ensured players were equipped with the tools and understanding to enter data and view their individual athlete monitoring and injury surveillance analysis detailed in the previous EPD App development chapter of this thesis.

4.2.5 Evaluation Procedures

4.2.5.1 RE-AIM Framework

The RE-AIM Framework (Glasgow, Vogt et al. 1999) was chosen to provide an evidence-based structure to evaluate the EPD App. As the framework was originally designed to assess public health interventions and their impact, the original definitions were contextualised for sport using the Sports Setting Matrix, provided by Finch and Donaldson (2010) and methods previously employed for the RE-AIM Framework by Ekegren, Donaldson et al. (2014) (Table 10). The *Evaluation* column of Table 10 outlines the metrics used to evaluate each dimension of the EPD App. Player (system-user) data was exported from the App throughout, to provide ongoing feedback to academy practitioners and Steering Group members on adherence levels, and then finally at the completion of the study period for the results section below. Data relating to the individual time spent using the EPD App from Login to Logout was also exported for analysis using Google Analytics (Google LLC) (see Appendices **Error! Reference source not found.**).

Table 10: The contextualised RE-AIM Framework.

DIMENSION	*ORIGINAL DEFINITION*	CONTEXTUAL APPLICATION	*EVALUATION METRICS*
Reach	Proportion of the target population that participated in the intervention.	What proportion of Academies and players would agree to use the EPD App?	Proportion of total Academies and Players that sign consent forms.
Effectiveness	Success rate if implemented as in guidelines.	Is the EPD App effective in providing an intervention of acceptable perceived-quality for the players to use?	Player uMARS assessment of EPD App.
Adoption	Proportion of settings, practices and plans that will adopt this intervention.	Of the players that agree to participate, what proportion will actually use the EPD App?	Proportion of players 'Reached' that complete 1-survey.
Implementation	Extent to which the intervention is implemented as intended in the real-world.	Of the players that agree to participate, what proportion will actually use the EPD as intended?	Proportion of players 'Reached' that complete 1-block of surveys.
Maintenance	Extent to which an intervention is sustained over time.	Of the players that agree to participate, what proportion will actually sustain use of the EPD App as intended?	Proportion of players 'Reached' that complete 3 or more consecutive survey blocks.

1. <u>Reach:</u> The Reach dimension explained the size and proportion of the overall cohort targeted and evaluated how successful the EPD App and implementation strategy were at attracting the required regional academies and their players to participate. The evaluation was split over two levels, 'Academy' and 'Player'. The 'Academy-level' was a proportion of the total 14 regional academies who completed the multi-level Club Briefing Sign-off process, while the 'Player-level' was a proportion of the total registered academy players within those academies that agreed to participate whom completed the online consent. The two levels were used to recognise that regional academies dictated whether players were first eligible to participate, and thus give context to the overall 'Reach' of the App and strategy. The remaining four levels referred to participant only data.
2. <u>Effectiveness:</u> See uMARS section.
3. <u>Adoption:</u> The Adoption dimension was the first measure of App use, and explained the number and proportion of players who, after agreeing to participate, actually used the EPD App. Adoption was represented as a proportion of 'Reach' and calculated as the number of players that completed

at least one 'Current Status' survey across the two seasons. The metric evaluated whether after completing consent, players successfully progressed to using the App. This illustrated both how successful the EPD App and strategy were at converting participation (Reach) into initial uptake, and therefore represented the baseline agreeableness of players to use the App.

4. Implementation: The Implementation dimension was the second measure of App use, and explained the number and proportion of players who, after agreeing to participate, actually used the EPD App as intended. Implementation was represented as a proportion of 'Reach' and calculated as the number of players contributing a single (consecutive or non-consecutive) data-block of 20 Current Status surveys from a possible 28-day period. This was referred to as a '20-block', which represented a 70% survey completion over a four-week period. The metric evaluated whether the initial adoption dimension translated to players using the EPD App as intended.
5. Maintenance: Maintenance was the final measure of App use, and explained the number and proportion of players who, after agreeing to participate, actually sustained their 'intended use'. Maintenance was represented as a proportion of 'Reach' and calculated as the number of players contributing three consecutive 20-blocks across the two seasons. The three consecutive 20-blocks was considered the minimum amount required to reliably model load-response-injury associations, and was based upon the current academy rugby union injury-risk, and that of an acceptable number of injuries captured to see small, moderate and large associations (Bahr and Holme 2003). The maintenance metric evaluated whether the players that implemented the App as intended, had the capacity to repeat this level of implementation, and therefore provide ongoing remote-athlete data capture.

4.2.5.2 User Mobile App Ratings Scale (uMARS)

The uMARS (Stoyanov, Hides et al. 2016) was chosen to represent the 'Effectiveness' dimension of the RE-AIM Framework and evaluated whether the EPD App was of acceptable player-perceived 'quality' and therefore an effective intervention for player use. The uMARS is the simplified, user version of the more detailed MARS tool (Stoyanov, Hides et al. 2015) and provides a reliable and evidence-based assessment specifically addressing the quality of health-related Apps (Stoyanov, Hides et al. 2016, McKay, Cheng et al. 2018, Soomro, Chhaya et al. 2019). Internal consistency (alpha=0.90) and interrater reliability (alpha=0.79) is deemed acceptable for use (Stoyanov, Hides et al. 2016). The tool comprises of 31 questions, mostly using a Likert-Scale format, and evaluates Apps on three domains: 1) Objective App Quality (Engagement, Functionality, Aesthetics, Information), 2) Subjective Quality (likelihood of recommendation to others, future use, overall rating), and 3) Educational Value and Behavioural Change (impact on knowledge, attitudes, awareness, behaviour). In order to make the tool specific to the App being evaluated, Question 9 (Gestural Design; taps, scrolls, pinches) and Section D (questions relating to high-quality information provided by App) were removed as these components were not featured in the EPD App. The tool was incorporated into an online survey (Online Surveys Copyright © 2019, Jisc) and distributed through the online survey system via a password protected email list generated from the initial participant consent forms. The survey required participants to complete 16 objective quality subscale questions. These sections covered Engagement, Functionality and Aesthetics of the App. They were then required to complete 4 subjective quality subscale questions and a further 6 subscale questions relating to the Educational elements (referred to as Perceived Impact items by developers) of the App (Does this App improve your; Awareness, Knowledge, Attitudes, Intention to Change, Help Seeking, Behaviour Change). Each question subscale was scored 1-5 (1 being the lowest score, 5 being the highest) and mean and median scores would be determined for individual sections, alongside a total App quality mean and median score with appropriate variation descriptors. A full description of the inventory can be seen in Appendices (uMARS Consent and Survey).

4.2.6 Data Analysis

Raw data from the EPD App, Google Analytics and uMARS online survey were exported into a Microsoft Excel v2013 template. Data was cleaned (duplicates deleted) and checked for normality. Reach data was calculated by a count of the total consents received using the pivot table function in Excel. The proportion displayed as part of the Reach measurement was the total consents received (n =) divided by the total registered academy players from participating academies. Current Status surveys were used to analyse the Adoption, Implementation and Maintenance dimensions as they were the first daily survey within the survey flow and were unchanged in terms of modifications throughout the study period. Counts for Adoption, Implementation and Maintenance (n =) were displayed, and the percentage was calculated as a proportion of player Reach.

The 20-block metric used within the Implementation and Maintenance dimensions represented an approximate 70% completion rate and was determined by recording the number of unique ‘Current Status’ survey dates, within a defined 28-day period (i.e. if players recorded surveys on 20-days or more within a 28-day period, their data was included. The 20-days or more could be both consecutive and non-consecutive. A script written in RStudio v2018 was used for to produce the analysis (see Appendices **Error! Reference source not found.**). RStudio was programmed to select a player from the cleaned export, then the corresponding date that player had completed a survey, then looked forwards 28-days, and backwards 28-days from this date. If 20 unique dates occurred in either direction, the player’s data was included. This process was repeated for Maintenance but using a 60-days or more within an 84-day period to display whether players had maintained intended use over three consecutive 28-day periods.

To calculate the uMARS Objective Quality Score, questions 6-16 (see Appendices uMARS Consent and Survey) from the online survey were included in the mean, standard deviation and median. To calculate Engagement, questions 6-10 were used, Functionality, questions 11-13, and Aesthetics, questions 14-16. To calculate the uMARS Subjective Quality Score, question 20 (‘What is your overall rating of this App?) was used. Educational Value scores were calculated from questions 21-26 (see Appendices uMARS Consent and Survey).

4.3 Results

Regional academy practitioners representing all 14 of the professional clubs in England were informed of the study at an April 2017 presentation. An Academy Briefing Document was then sent, inviting them to take part in the study from September 1st, 2017 to May 31st, 2019 (21 months, 637 days). Season-1 ran from September 1st, 2017 – May 31st, 2018 (9 months, 272 days) and was without the modifications to the EPD made throughout the development process outlined in the previous chapter. Season-2 included the modifications and ran from June 1st, 2018 – May 31st, 2019 (12-months, 364-days).

4.3.1 RE-AIM Framework Evaluation

A total of 999 players (mean ± SD age =15.5 ± 1.2 years) provided consent, and a total of 50647 'Current Status' observations across two seasons (n =21 months, n =637 days) were recorded. The average daily survey completion time was approximately 90 seconds, with completion times for the weekly survey flows (Life Stress and Performance Restriction) being on average 2 minutes. Players both started interacting with, and were removed from, the EPD App at varying timepoints throughout the two seasons. This represented the dynamic athlete development pathway, whereby players can be selected and deselected at varying points. Thus, players included in the results have varying overall exposure periods to the EPD App. The RE-AIM Framework evaluation in Table 11 displays the Player-level 'use' of the EPD App across both Season-1 and Season-2.

Table 11: RE-AIM Framework Evaluation

Domain	Proportion n= (%)
Reach	
Academy-Level n =14	9 (64%)
Player-Level n =1038	999 (96%)
Adoption **(% = proportion of Player-level Reach)**	781 (78%)
Implementation **(% = proportion of Player-level Reach)**	294 (29%)
Maintenance **(% = proportion of Player-level Reach)**	115 (12%)

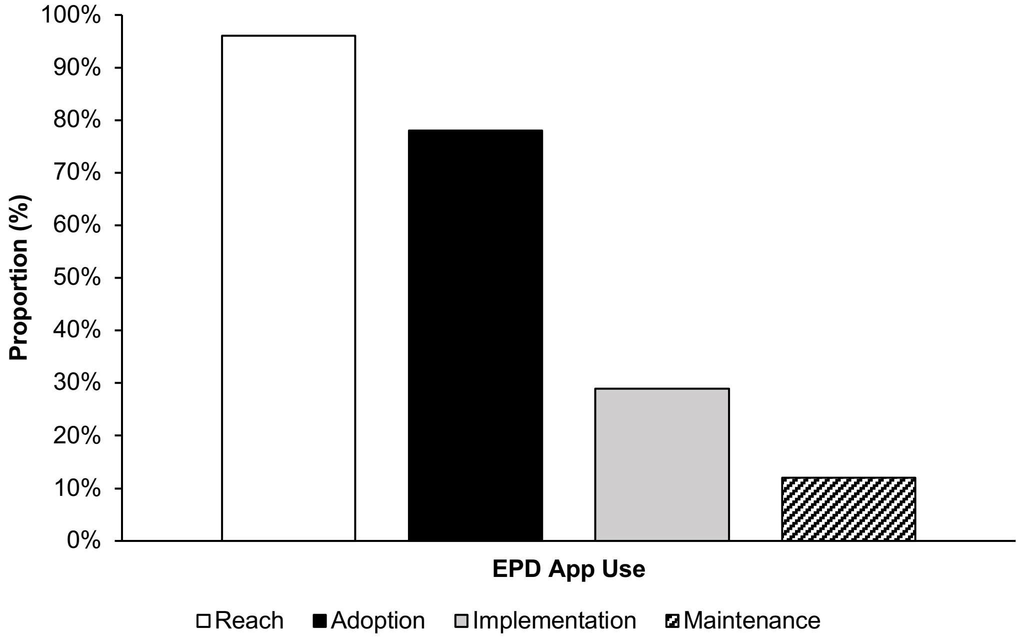


Figure 31: Player-level RE-AIM Framework Evaluation with Reach a percentage of total registered players and Adoption, Implementation and Maintenance as percentages of Reach

4.3.1.1 Reach

Academy Level Reach was n =8 (57%) throughout season-1. During the second year of the study, 3 regional academies dropped out, with 1 new regional academy being added, resulting in a total of n =6 (43%) academies being reached in season-2. Overall n =9 (64%) academies were reached throughout the study period. Player-level Reach was n =999 of the total n =1038 academy cohort, representing 96%.

4.3.1.2 Adoption

Adoption rates were 78% over the two seasons, which meant that 781 of the overall players Reached (n =999) completed the setup and registration process and successfully logged onto the EPD and completed at least one survey. This represented the proportion of players that went from agreeing to participate (Reach) to initially engaging in the App. The results show that 22% (n = 218) of the players Reached, did not Adopt the EPD App.

4.3.1.3 Implementation

Implementation rates were 29% over the two seasons, meaning 294 of the overall players Reached (n =999), used the EPD App as intended (minimum of 20-days within the 28-day period). This represented the proportion of players that went from agreeing to participate (Reach), successfully using (Adoption), and then to utilising the EPD as intended. The results show that 71% (n =705) of the players Reached, did not Implement the EPD App as intended. Compared to Adoption, Implementation rates dropped by 62% (n =487).

4.3.1.4 Maintenance

Maintenance rates were 12% n =115 over the two seasons, meaning 115 of the overall players Reached (n =999), maintained intended use of the EPD App for three or more consecutive 28-day periods (minimum 60-days from a possible 84-days). This represented the proportion of players that went from agreeing to participate (Reach), successfully using (Adoption), successfully using as intended, and then maintaining the intended use for three consecutive periods. The results show that 88% (n =884) of the players Reached, did not maintain Implementation rates. Compared to Implementation, Maintenance rates dropped by 61% (n =179).

4.3.2 uMARS Evaluation

The uMARS was sent to all n =999 consenting EPD App players. Players that responded (n =186) within the designated survey completion period, represented 19% of the total cohort and 10 out of the 14 regional academies (71%) (some players had moved academies but continued to use the App while at their new academy). Of the players providing evaluations 5.5% (n =10) were under-15 players, 30% (n =55) were under-16 players, and 64.5% (n =118) were under-18 players. Figure 32 illustrates the EPD App usage rates by the players that participated in the uMARS evaluation.

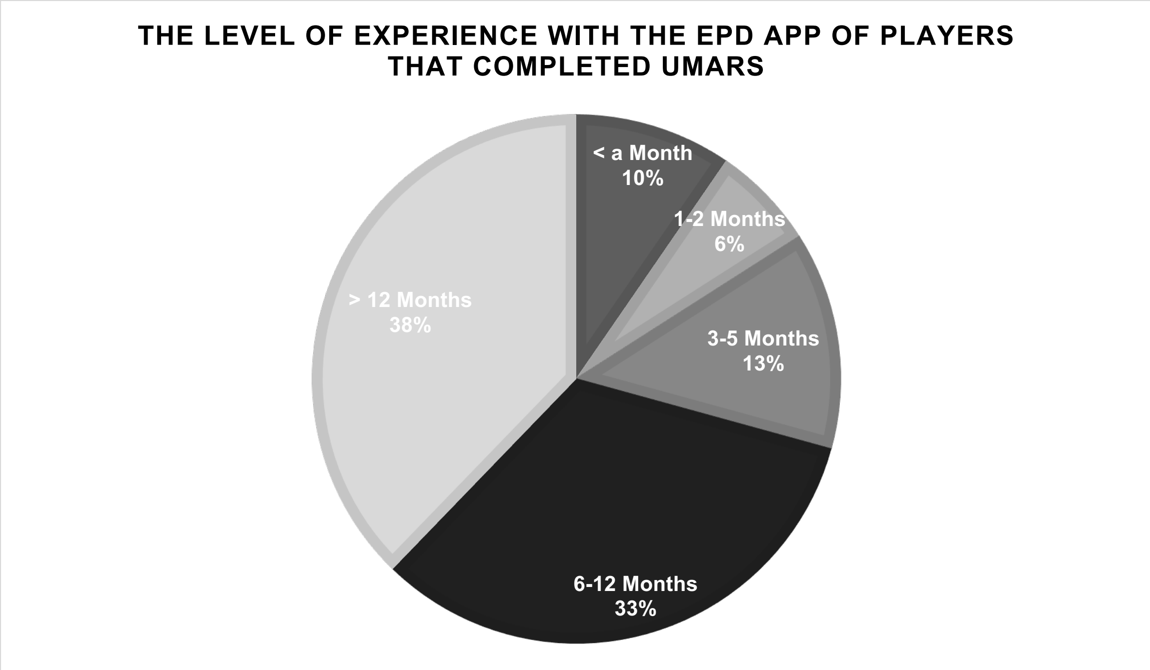


Figure 32: Description of Player EPD App usage as a percentage of the total players that completed the uMARS Evaluation (n =186).

4.3.2.1 EPD App Quality Scores

The overall EPD App Objective Quality Score (maximum score=5) was (mean ± SD)3.42 ± 1.05, (median=4). Of the three uMARS Objective Quality Score Sections (Engagement, Functionality and Aesthetics), 'Functionality' scored highest at 3.78 ± 0.97 (median=4), and 'Engagement' scored lowest at 3.09 ± 1.12 (median=3). The Subjective Quality Score (maximum score=5) was 3.21 ± 0.74 (median=3). A summary of these results can be seen in Table 12. The highest uMARS Objective Quality Score by Question was 'Ease of Use' 3.99 ± SD 0.98, (median =4), closely followed by 'Targeted' 3.93 ± 0.93, (median =4). The lowest was 'Entertainment' 2.56 ± 1.01, (median =3), followed by 'Customisation' 2.76 ± 1.08, (median =3). A summary of these results is illustrated in Figure 33.

Table 12: EPD App uMARS Objective and Subjective Quality Scores by Section and Overall, out of 5

N = 186	**Engagement**	**Functionality**	**Aesthetics**
Mean	3.09 ± 1.12	3.78 ± 0.97	3.61 ± 0.85
Median	3	4	4
Objective App Quality Score	3.42 ± 1.05 (Median=4) out of 5		
Subjective App Quality Score	3.21 ± 0.74 (Median=3) out of 5		

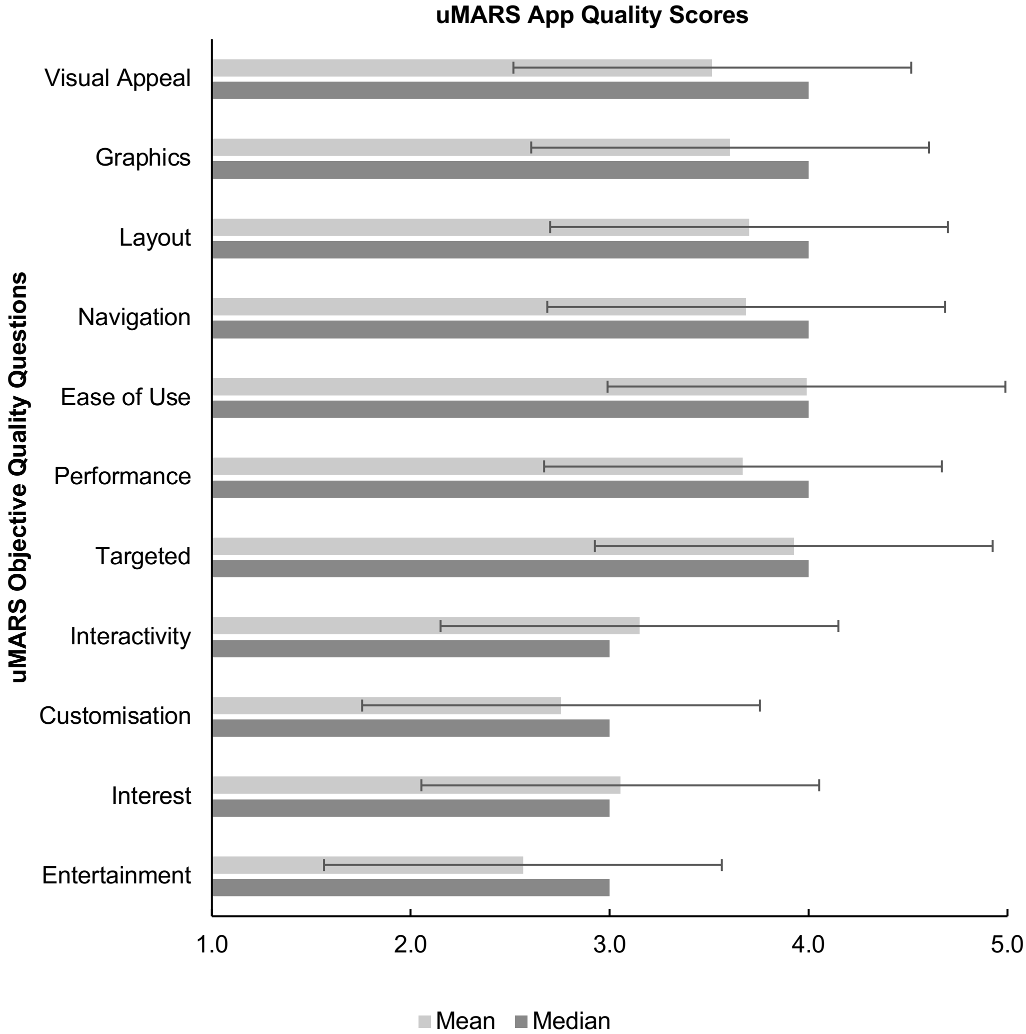


Figure 33: Mean, Standard Deviation and Median EPD App Objective Quality Scores by Question (questions 6-16) from the uMARS assessment

4.3.2.2 Educational Value and Behavioural Change Scores

The overall Educational Value Score was 3.43 ± 1.01, (median =3). The individual player scores ranged between highest;4.67 ± 0.52, (median =5), and lowest; 1.33 ± 0.82, (median =1). The highest Educational Value Question was 'Awareness' 3.62 ± 1.00, (median =4), followed by 'Knowledge' 3.51 ± 0.98, (median 4), and the lowest was 'Intention' 3.31 ± 1.01, (median =3), followed by 'Help Seeking' 3.36 ± 1.01, (median =3). Figure 34 shows a summary.

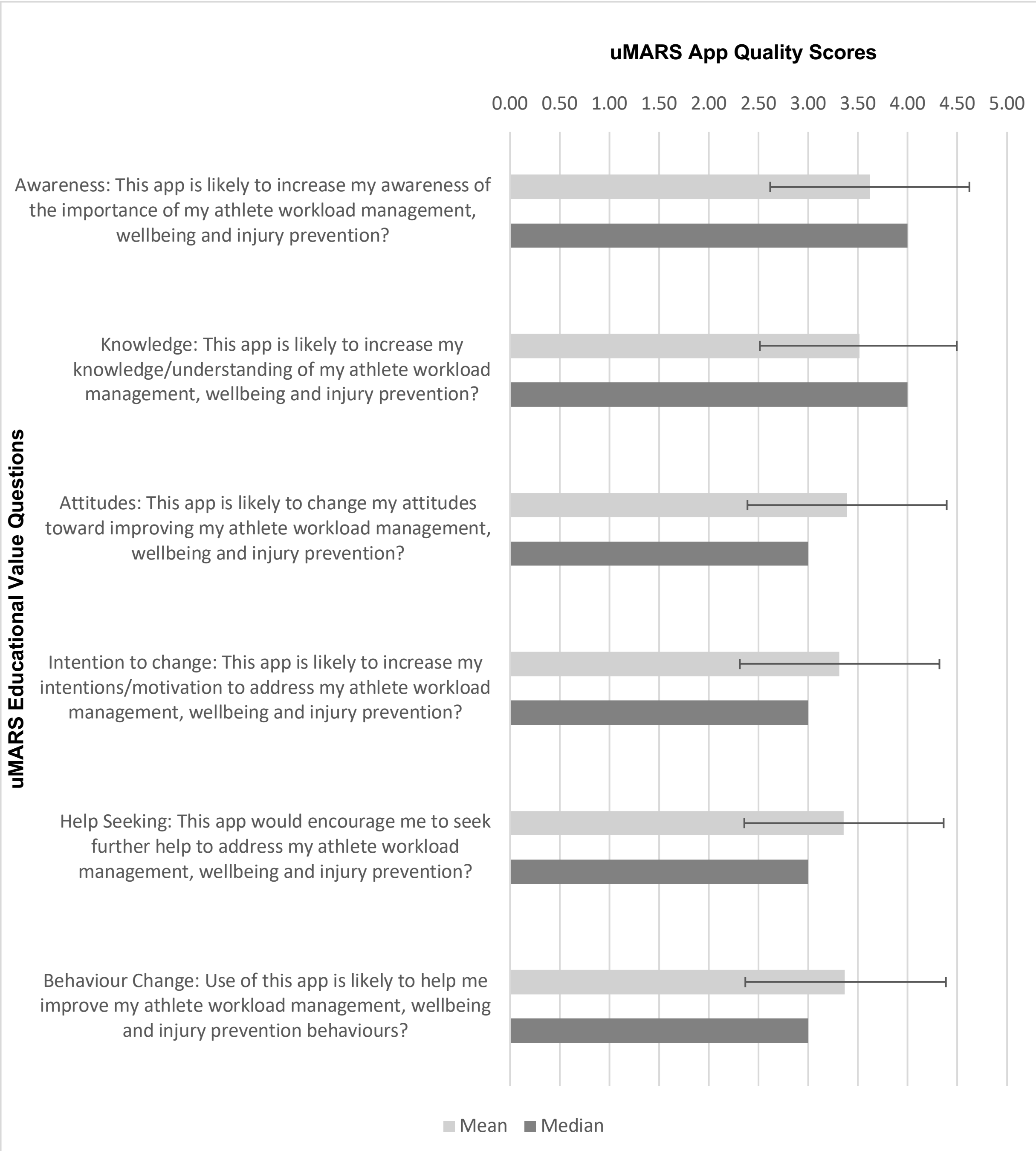


Figure 34: Mean, Standard Deviation and Median EPD App Educational Value Scores by Question from the uMARS assessment (Questions 21-26)

4.4 Discussion

The purpose of this study was to evaluate a bespoke athlete monitoring and injury surveillance smartphone application (EPD App) to inform future development and implementation strategy in a remote-athlete, academy rugby union setting. Current best practice implementation science suggests that an interventions impact is a function of both its 'use' and 'effectiveness' (Donaldson, Lloyd et al. 2017). The study therefore aimed to report on 1) player-use, and 2) player-perceived-quality metrics to provide insight into the acceptability of both the EPD App and its implementation strategy. To support a systematic and evidence-based approach, an established public health framework (RE-AIM) and specifically designed smartphone application assessment tool (uMARS) was employed as evaluation methods. The main finding from this study was that early, representatively high levels of Reach and Adoption, together with strong ratings of 'functionality' and 'ease-of-use' did not translate into a majority of participants implementing and maintaining their usage as intended. Another interesting finding was that while the EPD App was not meant to be used for educational purposes, it was likely those that used the App perceived themselves to have gained a greater 'awareness' and 'knowledge' of their personal workload management, wellbeing and injury prevention.

The importance of athlete monitoring and injury surveillance data to improving performance and reducing injury-risk is well documented (van Mechelen, Hlobil et al. 1992, Finch 2006, Finch 2012, Drew and Finch 2016, Soligard, Schwellnus et al. 2016, Claudino, Capanema et al. 2019), however, research into the successful implementation of the methods to capture this data has only recently emerged (Ekegren, Donaldson et al. 2014, Saw, Main et al. 2015b, Saw, Main et al. 2015c, Saw, Kellmann et al. 2017, Ronnby, Lundberg et al. 2018, Duignan, Slevin et al. 2019, Neupert, Cotterill et al. 2019, Soomro, Chhaya et al. 2019). Even with this recent growth, only two studies have previously used evidence-based evaluation tools such as the RE-AIM Framework (Ekegren, Donaldson et al. 2014) and uMARS (Soomro, Chhaya et al. 2019) within their study designs. At the time of writing, this appeared to be the first study to utilise both the RE-AIM Framework and uMARS together to evaluate an App-based sporting intervention. Most other sporting studies have chosen to employ qualitative, interview-style research designs to ascertain delivery-agent, coach or athlete perceptions surrounding the facilitators and barriers to implementation, and provided basic adherence or compliance metrics commensurate with the Reach and Implementation dimensions (Saw, Main et al. 2015b, Saw, Main et al. 2015c, Ronnby, Lundberg et al. 2018, Duignan, Slevin et al. 2019, Neupert, Cotterill et al. 2019). Only one study to date has fulfilled both an extensive RE-AIM evaluation together with evidence-based qualitative investigation into an athlete monitoring and injury surveillance system (Ekegren, Donaldson et al. 2014). Another study utilising an App-based neuromuscular training program for ankle sprains was the only other App-based sporting study found to use a similarly comprehensive RE-AIM and qualitative research design (Vriend, Coehoorn et al. 2015). Where studies have considered implementation issues across sporting interventions generally, it has typically been a minor component, whereby a systematic approach that can be easily replicated and compared is lacking (O'Brien and Finch 2014). The novelty of the current study and lack of directly comparative research is therefore a consideration.

After completing a comprehensive intervention and study briefing process, a total of 9 out of the 14 regional rugby union academies in England (64%) agreed to participate. A key reason for non-participation was a lack of perceived added value over current practices. While previous feedback, together with an overall lack of empirical evidence within academy rugby union (Trewartha and Stokes 2015, Viviers, Viljoen et al. 2018, Till, Weakley et al. 2020) had suggested a distinct desire and need for the EPD App technology, it seemed that in the time it had taken to develop the EPD App, and an appropriate implementation strategy, a proportion of academies had either re-evaluated their current needs, and/or developed their own in-house solutions. Across sports, standardised and ongoing athlete monitoring and injury surveillance systems are still considered rare due to the many context-based differences between, and within each sport (Ekegren, Gabbe et al. 2016, Shaw, Orchard et al. 2017). Athlete development pathways, such as the regional rugby union academy system in England are particularly complex given, they intersect participation, talent development and professional elite sections of sport, and are engaged with a large group of stakeholders (parents, schools, clubs, academies, international teams, professional clubs). This means common consensus and alignment on innovations can be time-consuming and difficult to manage. Comparative Academy-level Reach across single club/team/academy settings has traditionally been higher than in this study (mean =82%, range =40.3 – 100%) (O'Brien and Finch 2014), however a large range suggests contextual and methodological factors may influence results. When multiple remote-athlete settings are examined matching this study design more closely, Reach results appear to resemble this study's findings more closely (Ekegren, Donaldson et al. 2014). This suggests Academy-Level Reach within this study could be considered reasonably typical and even above average considering some studies define Reach as participants or settings sent information or purely expressing awareness of interventions, not actively committing to participation (Poulos and Donaldson 2012, Ekegren, Donaldson et al. 2014). While it seemed the comprehensive, multi-level development and implementation of the EPD App appeased a majority of regional academies, resulting in a representative sample for evaluation purposes, it did not attract all available settings, which, depending on the organisational benchmarks set, may not be considered successful. This suggests that more than collaboration and stakeholder engagement is needed to successfully Reach settings and consideration should be made to setting/organisational alignment within areas such as overall purpose, strategy and key performance indicators (Saw, Kellmann et al. 2017).

From the representative sample of academies that agreed to participate, 999 players (mean-age =15.5-years ± 1.2) completed consent across two-seasons (21 months) representing a Player-level Reach of 96%. This suggested a positive evaluation outcome as comparative Player/Participant-level literature across team ball sports is shown to be on average lower =83.2% (range 68.3 – 100%) (O'Brien and Finch 2014), with another sports injury study using an App-based intervention in the general public showing Reach results can be as low as 2.6% (Vriend, Coehoorn et al. 2015). Using sports and recreation industry standards derived from non-peer-reviewed research, Reach results are shown to be on average 68% (participants consenting to receive notifications) (Airship 2016). The successful Player-level Reach results were most likely due to the combined efforts of the regional academies and researchers, together with a relatively simple online, password protected consent process. While it was up to the players and their parents to consent to using the EPD App, they were most likely influenced by their academy and coaches who had already committed to participating, and therefore communicated a strong initial buy-in. Athletes have been shown to be particularly influenced by their coaches buy-in to athlete monitoring and surveillance practices (Duignan, Slevin et al. 2019, Neupert, Cotterill et al. 2019) with this even more apparent for youth, team sport athletes such as academy rugby union players (Saw, Main et al. 2015b). This could also be amplified as many of the young athletes would actively be trying to maintain and advance their selection chances within the talent pathway and see this as a part of buying into club culture.

The Adoption dimension was the first player-use metric and sought to evaluate how successful the EPD App and strategy were at converting the participation (Reach) and player-perceived-quality ratings (effectiveness) into initial uptake. Adoption therefore also represented the baseline agreeableness of players to use the App. Of the players Reached, 78% (n =781) completed the setup and registration process and logged in to complete at least one survey. This meant 22% (n =218) of players were not converted to using the App. While Adoption rates across team sports are on average typically lower (mean =64%, range =37 – 69%) they are also typically under-reported compared to the Reach and Implementation dimensions (O'Brien and Finch 2014), meaning the generalisability of the findings are questionable. Comparatively lower Adoption rates have been found within a study matching the remote-athlete setting and intervention (injury surveillance online system) whereby an Adoption average of 44% was reported, however, within a particular arm of the study that provided full implementation support, showed a 68% Adoption rate. Adoption rates have also been shown to be higher than this study's findings whereby an App-based neuromuscular training program showed a 94% (Vriend, Coehoorn et al. 2015). Similar to Player-level Reach, it would seem the Adoption results are above average based on the literature available, however, the overall lack of studies reporting Adoption makes this dimension harder to evaluate. It would seem the strong levels of perceived 'Functionality' and 'Ease-of-Use' exhibited within the Effectiveness dimension contributed to an acceptable conversion of players to actively using the EPD App. The perceived task self-efficacy levels amongst staff and players relating to using the EPD App could also have supported the initial Adoption rates. Common to health behaviour research, a participant's perceived understanding and ability to utilise an intervention (task self-efficacy) can lead to a greater intention to participate and initially adopt an intervention (Zhang, Zhang et al. 2019). The EPD App was built with multi-level practitioner and management input and based upon commonly used monitoring and surveillance practices within these Academies (West, Williams et al. 2019). It was therefore highly likely the coaches, staff and players had already been aware and previously exposed to such practices. The systematic nature of the familiarisation process whereby players and staff were provided opportunities to test the EPD App, ask questions and problem-solve with the support of researchers may have further facilitated this. These factors were all considerations of the development and implementation strategy and therefore the EPD App can be seen to show positive evaluation outcomes with reference to reducing the barriers to Reach and Adoption in academy rugby union.

The Implementation and Maintenance dimensions were the other two player-use metrics that sought to evaluate whether the initial representatively high Reach, Adoption and perceived 'Functionality' results were converted into 'use as intended' and then 'sustained use'. The EPD App was designed to be used daily with surveys taking between 90-seconds and 2-minutes to complete. This was especially important for collecting information on workload and general activity exposure as substantial missing data could lead to erroneous calculations. A specific metric was therefore attached to the Implementation dimension meaning that if 20-days within a 28-day block (20-block) was completed (70% adherence) this would qualify as 'use as intended' (Implementation), and if this was sustained for three consecutive 28-day blocks this would qualify as 'sustained use' (Maintenance). While previous athlete monitoring research in academy players has succeeded in complete, daily self-report data-sets (Phibbs, Jones et al. 2018) this was over a far shorter in-season period within a single academy, whereas this study spanned multiple academies and ongoing data collection. It was decided relaxing the restrictions on intended use would still give a strong indication consistently, while allowing for potential data imputation methods to be incorporated (Dong and Peng 2013, Jakobsen, Gluud et al. 2017).

While the Reach and Adoption dimensions showed positive signs, the Implementation (29%) and Maintenance (12%) dimensions showed comparatively poor results and represented the largest decline across the dimensions. Implementation rates across team sport studies can range between 19 – 90% (O'Brien and Finch 2014), and while a distinct lack of available research makes Maintenance hard to ultimately determine, results show between 4 – 18% (Ekegren, Donaldson et al. 2014). While large ranges and typically lower results exist across Implementation and Maintenance, suggesting these dimensions represent a potential tipping point for many interventions, the magnitude of the declines in this study are concerning. The decline showed that 71% (n =705) of the players Reached (n =999), did not Implement the EPD App as intended. Compared to its previous dimension (Adoption), Implementation rates dropped by 62% (n =487), with a similar drop-off from Implementation to Maintenance (61%) (n =179). Non-peer-reviewed industry research has found that across 63-million App-users, an average of 54% who initially download an App (representative of Reach and Adoption) will 'churn' (cease to use the App) after 90-days, even with optimal marketing and messaging (Airship 2016). The research conducted suggests, while a major concern within the current study, largescale declines within these dimensions are not to be unexpected, and though Apps provide a promising intervention in reducing many barriers related to Reach and Adoption, they do not necessarily guarantee Implementation and Maintenance. This notion tends to be supported by previous online and App-based intervention literature (Ekegren, Donaldson et al. 2014, Vriend, Coehoorn et al. 2015, McKay, Cheng et al. 2018, Ronnby, Lundberg et al. 2018, Soomro, Chhaya et al. 2019). Furthermore, while it has been shown interventions with systematic, context-driven implementation strategies significantly improve RE-AIM dimensions, those that display a need for regular commitment and application as part of their Implementation and Maintenance metrics (such as in this study), have continued to encounter challenges (Ekegren, Donaldson et al. 2014, Donaldson, Gabbe et al. 2019). Given athlete monitoring and injury surveillance is reliant upon the ongoing capture of high-quality data (Finch 2006) it is essential for the EPD App to display the ability to not only reduce barriers to initial uptake and usage but also implement and maintain these benefits as intended with a high level of quality.

Reasons surrounding the challenges faced within the Implementation and Maintenance dimensions for athlete monitoring and injury surveillance interventions can be conceptualised into two key categories 1) the intervention itself (e.g. the complexity and time-resource required to operate and navigate App), and 2) the socio-environment the intervention is placed (e.g. the interpersonal, cultural, organisational and governance related factors that influence the individual beliefs, motivation and purpose behind the intervention). When addressing the declines in Implementation and Maintenance from an intervention standpoint, high ratings of ‘Functionality’ coupled with a successful translation of Reach to Adoption dimensions suggests the intervention did not pose a barrier to players operating the App. While barriers seemed limited on a player-level they may have been present for the staff and coaches managing the EPD App and associated data. A significant underestimation by support staff surrounding system-use and overall implementation requirements has been suggested as a key barrier to implementation success, with this being present even after educational support (Duignan, Slevin et al. 2019, Neupert, Cotterill et al. 2019). While it was thought the multi-level stakeholder engagement and support provided to each academy throughout the development and implementation stages would limit this underestimation, staff evaluations were not accounted for, so it is hard to truly determine. It therefore seems more likely socio-environmental factors could have been at play. A lack of interpersonal communication and practical feedback loops connecting players, staff and management to the data is commonly cited as a socio-environmental barrier to implementation (Saw, Main et al. 2015c, Saw, Kellmann et al. 2017, Neupert, Cotterill et al. 2019). Having access to the available time and staffing resources or education are commonly cited as reasons for this (O'Brien and Finch 2014, Saw, Kellmann et al. 2017). However, these can all be considered products of broader socio-environmental factors such as the overall purpose behind implementing athlete monitoring and injury surveillance systems in the first place, together with whether the necessary infrastructure, motivation and incentives are in place (Saw, Kellmann et al. 2017). These factors would therefore need to be addressed to fully execute a successful implementation strategy. While the EPD App addressed an agreed barrier and was provided free of charge, together with technical and strategic support, there may not have been the overarching organisational alignment of purpose, incentives or infrastructure in terms of appropriate education and prioritisation of time and human resource to successfully translate Reach and Adoption into Implementation and Maintenance.

The effectiveness dimension sought to evaluate whether the EPD App was of acceptable quality for use by the players by assessing a range of App engagement, functionality, aesthetic, educational value and behaviour change factors. A total of n =186 players completed the uMARS assessment tool showing an overall EPD App objective quality score of 3.42 ± 1.05 (Median=4) out of 5 and subjective 3.21 ± 0.74 (median=3) out of 5 which compares favourably with another App-based athlete monitoring and injury surveillance system developed for cricket (objective =3.6, SD 0.5 and subjective =3.1 ± 0.7) (Soomro, Chhaya et al. 2019). EPD App 'Functionality' ratings were above average (>2.5) (mean =3.78 ± 0.97, median =4) due to specific App quality measures of 'Ease of Use' (mean =3.99 ± 0.98), median =4), and 'Navigation' (mean =3.69 ± 0.91), median =4) which suggested system-use factors for the participants was not a barrier to uptake. Barriers to easily using, understanding and navigating App-based and online systems within athlete monitoring and injury surveillance interventions are routinely noted as key drivers of participants and settings declining usage or lack of uptake entirely (Ekegren, Donaldson et al. 2014, Vriend, Coehoorn et al. 2015, Ronnby, Lundberg et al. 2018, Duignan, Slevin et al. 2019). The lowest specific measures for the EPD App were 'Entertainment' (mean =2.56 ± 1.01), median =3), followed by 'Customisation' (mean =2.76 ± 1.08), median =3). These constructs can lay claim to supporting individual drivers of implementation and sustained participant engagement most commonly through the 'gamification' of App's, whereby in-built games or challenge elements are designed, together with the ability to customise profiles and settings to individual needs (Sardi, Idri et al. 2017, Lyons, OBroin et al. 2018). This leads to greater personal investment and attachment and has also previously been noted as a key facilitator in interview style qualitative evaluation studies of App-based and online interventions (Ekegren, Donaldson et al. 2014, Vriend, Coehoorn et al. 2015, Duignan, Slevin et al. 2019, Soomro, Chhaya et al. 2019). It was to be expected these scores would rate the lowest as the App was not designed with these factors in mind. The Entertainment and Customisation scores, while the lowest for this study, both do not present as below average scores (<2.5) on the uMARS scale, so it is questionable whether these scores would substantially impact EPD App use compared to other factors.

An interesting finding within the uMARS results was that while the EPD App was not designed as an education tool, players perceived they had gained both greater awareness and knowledge through using the App. Educational value scores relating to Awareness (mean =3.62 ± 1.00), median =4) and Knowledge (mean =3.51 ± 0.98), median 4) showed above average results suggesting regardless of overall use, the players surveyed reported as having improved their understanding and management of workload, wellbeing and injury. Studies by Saw, Main et al. (2017) and (Duignan, Slevin et al. 2019) both show preliminary evidence to suggest athletes develop greater self-awareness and regulation capacities through engaging in athlete monitoring. It is also not surprising that athletes exposed to monitoring and surveillance early on in their careers display greater self-efficacy and engagement in the practices leading to improved compliance and high-quality datasets (Saw, Main et al. 2015c, Duignan, Slevin et al. 2019, Neupert, Cotterill et al. 2019). This is an interesting finding because the target of traditional athlete monitoring and injury surveillance practices, and that of this study, has been on the capture of high-quality data for performance and epidemiological purposes, however there may be hidden health and performance benefits to engaging in the process regardless of whether the data is of consistent high-quality. The process of reflecting on certain activities, their impact on you physically, mentally and emotionally and the positive and negative outcomes associated (performance, injury, illness etc) is the mechanism in which self-awareness and regulation abilities are developed and have been shown to improve talent transfer, performance, and aspects of wellbeing in youth athletic populations (Jonker, Elferink-Gemser et al. 2010, Nicole and Natalie 2015). Self-awareness and regulation are also the basis for which mindfulness practices are shown to influence mental health and performance across all walks of life (Spijkerman, Pots et al. 2016). Building the self-awareness and regulation capacities that are found to be facilitated through athlete monitoring and injury surveillance practices is also of particular relevance to youth athletes given they may have to manage these aspects as part of a professional career. While high-quality, consistent data is obviously important to developing interventions and best-practices, the life-skills generated by young people through athlete monitoring and injury surveillance could also result in greater levels of awareness and regulation regarding their personal wellbeing, readiness to perform and the factors leading to illness or injury, allowing them to better navigate not only their sport, but also life events in general.

4.5 Limitations

Employing multi-setting, and multi-level, longitudinal implementation study designs in the real-world is challenging, but necessary to translate research into practice. Though a majority of regional academies were Reached, not being able to Reach all available regional academy settings may have implications on the overall representativeness, usage and quality. This could have both positive, and negative, whereby academies either have methods in place that showed better results and therefore could have contributed positively, or they did not see the added value or have the infrastructure in place that would have contributed to poorer results. While noted in the methods of this study, obvious limitations for consideration are the changing EPD App features in season-two, differing data collection start and end points of players, and the pooling of data across both seasons. While based upon previous research designs, the data analysis within this study could have been further explored to better describe the data collected. Reporting on what points throughout the two seasons data was attained, analysing seasons independently and ascertaining the significance and confidence intervals surrounding uMARS scores could have been utilised to strengthen statistical reporting. Another limitation was that both use, and quality metrics were only collected at a Player-level. While Reach was split over two levels (academy and players), doing this across all the RE-AIM dimensions particularly with the uMARS and Effectiveness dimension could have provided a far more comprehensive multi-level dataset. Further to this point, a qualitative, semi-structured interview approach could have been employed to further elaborate on some of the key dimensions and findings. This is especially relevant in reference to gaining valuable insight surrounding the socio-environmental facilitators and barriers hypothesised.

4.6 Conclusion

The EPD App and its associated implementation strategy when evaluated across the RE-AIM dimensions displayed representatively acceptable Reach (96%) and Adoption (78%) metrics however these did not translate well to the Implementation (29%) and Maintenance (12%) dimensions which experienced substantial declines in usage. When compared to the available literature, both Reach and Adoption could be considered well above average providing evidence for the utility of the EPD App and implementation strategy in reducing the barriers to initial engagement and uptake in athlete monitoring and injury surveillance practices. This could be due to above average 'Functionality' and 'Ease-of-Use' scores within the Effectiveness dimension that were facilitated by the implementation strategy initiated resulting in players perceiving themselves to have high task-self-efficacy, a key driver of initial engagement and uptake. Large ranges in Implementation success, and an overall lack of evidence concerning the Maintenance dimension made comparative evaluations of these dimensions difficult to ultimately determine, however the declines at each of these dimensions would be considered substantial. This suggested while the EPD App and associated strategy were successful at the Reach and Adoption dimensions, they were unsuccessful in delivering Implementation and Maintenance success. Given an inability to understand and use the EPD App seemed unlikely a major concern, the only identifiable intervention-based consideration could be a lack of engagement features within the App. While the EPD App was provided free, with both technical and strategic support to regional academies in order to best manage and utilise the App and data, a combination of socio-environmental factors such as staff education or communication channels, organisational alignment, clarity of purpose and incentives may have limited success. Though it seems App-based athlete monitoring and injury surveillance systems show great utility in removing barriers to remote-athlete data capture, it seems they do not guarantee sustained use as intended even with a systematic implementation strategy. Greater focus therefore needs to go into better understanding or re-imagining the Implementation and Maintenance dimensions together with creating the necessary infrastructure to facilitate these dimensions.

5 CHAPTER FIVE

General Discussion, Practical Implications and Future Directions

5.1 Introduction

Athlete monitoring and injury surveillance practices enable researchers and practitioners to gather the biopsychosocial and epidemiological data needed to inform evidence-based performance and safety practices (Finch 2006, Bourdon, Cardinale et al. 2017). Rugby Union, a global team sport particularly reliant upon athlete monitoring and injury surveillance due to its comparatively higher injury-risk to other sports, has previously indicated a distinct need for innovation in this space regarding its youth development pathways (Trewartha and Stokes 2015, Till, Weakley et al. 2020). In England, the regional academy system predominantly operates as a remote-athlete development pathway meaning athletes spend their development time across a multitude of settings (e.g. school, club, county, academy, international) (Phibbs, Jones et al. 2018). This presents many logistical barriers which currently have resulted in a distinct lack of ongoing, longitudinal evidence to inform practice in this setting, particularly as it relates to injury. This thesis therefore aimed to investigate reducing the barriers to remote-athlete monitoring and injury surveillance in English academy rugby union. In doing so, several novel research questions were posed in Chapter One of this thesis, which were subsequently addressed in Chapters Two, Three and Four. The purpose of this present Chapter is to synthesise the key findings and to critically assess the extent to which the research questions posed have been addressed. Through this approach, the original contribution to current research knowledge in this area, as well as the application of the findings to both rugby, and other sport's remote-athlete development pathways is outlined. Finally, key considerations in delivering similar research in the future, and potential approaches to further both the applied and academic fields are offered.

5.2 Addressing the Research Questions

Whilst an increased commentary and push for consensus statements in the areas of athlete monitoring and injury surveillance has provided both guidelines and greater understanding (Fuller, Molloy et al. 2007, Soligard, Schwellnus et al. 2016, Bourdon, Cardinale et al. 2017, Gabbett, Nassis et al. 2017, Quarrie, Raftery et al. 2017), largescale, longitudinal research and practice in this area outside of elite sport is still considered rare (Ekegren, Gabbe et al. 2016). This may be partly due to a focus on fitting existing guidelines and best-practices to the context, rather than combining the evidence-base and contextual factors to re-imagine ways to balance both. Implementation science, the study of translating research into applied practice, suggests finding solutions should first be explored by researching key knowledge domains through the lens of the multi-level stakeholders and environment in which your research is set (Fixsen, Blase et al. 2009, Donaldson and Finch 2013). These considerations therefore led to the first research question.

i. Considering the current sports performance and injury research, what are the viable options to capturing remote-athlete monitoring and injury surveillance data?

In order to reflect the growing acceptance that sports performance and injury are in fact emergent outcomes from complex systems, research and development should look to embrace strategies that include whole of sport approaches that focus on pattern-recognition profiling, rather than solely isolating variables, and involve top down, middle out, and bottom up implementation and evaluation (Bekker and Clark 2016, Bittencourt, Meeuwisse et al. 2016, Glazier 2017). Current sports performance and injury prevention research therefore advocates capturing data relating to not only a) biopsychosocial descriptors of training and competition stress-response, and b) injury epidemiology, but also c) the contextual environment (multi-level ecological data), to represent the multi-faceted nature of sport and implementation best-practice (Finch 2006, Donaldson and Finch 2013, Bourdon, Cardinale et al. 2017, Glazier 2017).

Key Findings:

- Smartphone App-based, athlete monitoring and injury surveillance systems utilising evidence-based self-report methods presented as the most cost-effective and viable option to meeting both the research and contextual needs.
- Self-reported methods embedded in smartphone Apps such as Session-RPE (Athlete Load), Wellbeing and Life Stress Questionnaires (Athlete Response) and the Oslo Sports Trauma Research Centre Injury Questionnaire were considered currently the most ecologically valid, and evidence-supported methods as they provide rich datasets, are highly adaptable to different settings and activities, and are simple to understand and use.

While the utility of embedding self-report methods into App-based interventions and mobile health is promising, research into the development and implementation of these systems within sporting contexts is limited and only recently been attempted (van Mechelen, van Mechelen et al. 2014, Duignan, Slevin et al. 2019, Raihana, Radin et al. 2019, Soomro, Chhaya et al. 2019, Holmes, Sherman et al. 2020). The lack of a systematic and evidence-based approach is a key theme limiting this field currently. This led to the second research question.

ii. Are there evidence-based approaches to planning and evaluating the design and implementation of bespoke athlete monitoring and injury surveillance strategies?

Research evidence alone is insufficient to develop implementable sports innovations such as App-based athlete monitoring and injury surveillance systems. It is therefore suggested innovations also consider aligning multi-level development, implementation and evaluation strategies to improve successful innovation diffusion (Rogers, Singhal et al. 2009, Donaldson and Finch 2013).

Key Findings:

- The Six-Step Intervention Development Process (Donaldson, Lloyd et al. 2016) provides an evidence-based and generalisable structure to systematically plan the design and development of new sporting innovations with the context in mind.

- The RE-AIM Framework, its associated Sports Setting Matrix (Finch and Donaldson 2010) and uMARS (Baptista, Oldenburg et al. 2017) assessment tools can be used to both support planning, and complete a multi-level evaluation of the designed sporting intervention, and associated implementation strategy.

Documenting the steps to developing interventions is useful when evaluating the overall implementation strategy and connecting this to key objectives and return on investment. The process promotes transparency in how researchers and stakeholders collaborate during the intervention development phase, and then provides a more systematic basis in which all parties can evaluate, iterate and improve. Alongside describing the development process, key evaluation metrics relating to 1) participant-use, and 2) perceived-quality are considered important to understanding the facilitators and barriers to successful implementation and sustained use (Rogers, Singhal et al. 2009, Donaldson and Finch 2013). For these reasons it was important to address questions three and four of this thesis.

iii. What are the processes involved in developing a bespoke, multi-squad, athlete monitoring and injury surveillance system and implementation strategy in academy rugby union?

Innovations development, and successful implementation is considered a complex, iterative process that requires evidence, experience and the ability to align these to contextual factors (Rogers, Singhal et al. 2009, Donaldson, Lloyd et al. 2016, Braithwaite, Churruca et al. 2018). To capture these considerations, Chapter Three of this thesis utilised the first four steps of the Six-Step Intervention Development Process proposed by Donaldson, Lloyd et al. (2016) to outline the development and implementation strategy of an App-based athlete monitoring and injury surveillance innovation.

Key Findings:

- Following key components of the Six-Step Intervention Development Process; 1) reviewing the existing literature and context, and 2) blending expert opinion with 3) end-user feedback, it was possible to deliver a bespoke athlete monitoring and injury surveillance smartphone application, the Elite Player Development (EPD) App and a context-driven implementation strategy that achieved multi-level sign-off.

- Blending expert opinion with end-user feedback allowed successful navigation of several instances when scientific rigour was placed against context-specific applicability.
- End-user feedback tended to follow a timeline of first technology/system issues, then a lack of appropriate environmental/infrastructure requirements and finally to particular personal perceptions and individual knowledge and understanding.
- Providing avenues for 1) multi-level sign-off, education and supporting infrastructure, that 2) engages all stakeholders by connecting key feedback and value loops were considered key factors of implementation.

Developing multi-level, context-driven and efficacious sporting innovations and implementation strategies however do not always guarantee success, and that is why mapping out the process and delivering multi-level participant-use and perceived-quality evaluations are important to reducing the innovation-implementation gap.

iv. Can measures of participant-use and perceived-quality be employed to systematically evaluate athlete monitoring and injury surveillance system innovations?

Current best practice implementation science suggests that an interventions impact is a function of both its ‘use’ and ‘effectiveness’ (Donaldson, Lloyd et al. 2017). According to the Diffusion of Innovations theory, the ‘perceived’ quality and effectiveness of an intervention is a greater driver of implementation than the research evidence itself (efficacy) (Rogers, Singhal et al. 2009). Chapter Four of this thesis therefore reported on 1) player-use, and 2) player-perceived-quality metrics to evaluate the acceptability of both the EPD App and its implementation strategy. The RE-AIM Framework, its associated Sports Setting Matrix (Finch and Donaldson 2010) and uMARS (Baptista, Oldenburg et al. 2017) were employed as evaluation tools.

Key Findings:

- The EPD App and associated implementation strategy were successful at the Reach (96%) and Adoption (78%) dimensions, however they were considered unsuccessful in delivering Implementation (29%) and Maintenance (12%), and ultimately full innovation diffusion.

- Above average (>2.5) EPD App ‘Functionality’ scores (mean =3.78 ± 0.97, median =4) due to specific App quality scores of ‘Ease of Use’ (mean =3.99 ± 0.98), median =4), and ‘Navigation’ (mean =3.69 ± 0.91), median =4) suggested an acceptable level of player-perceived task self-efficacy, meaning system-use factors for the participants were not a barrier to uptake and continued use.
- Educational value scores relating to ‘Awareness’ (mean =3.62 ± 1.00), median =4) and ‘Knowledge’ (mean =3.51 ± 0.98), median 4) showed above average results suggesting regardless of overall use, the players surveyed reported as having improved their understanding and management of workload, wellbeing and injury.
- A combination of socio-environmental factors such as staff education or communication channels, organisational alignment, clarity of purpose and incentives may have limited successful complete diffusion.

Though it seemed App-based athlete monitoring and injury surveillance systems show great utility in removing barriers to remote-athlete data capture, this did not guarantee sustained use as intended, even with a context-driven implementation strategy. Greater focus therefore needs to go into better understanding or re-imagining the Implementation and Maintenance dimensions together with creating the necessary infrastructure to facilitate these.

v. Are there key development and implementation considerations when employing a smartphone application-based athlete monitoring and injury surveillance system in academy rugby union?

Key Findings:

- Traditionally trying to fit efficacious interventions to applied settings has provided more barriers than solutions. Starting with the context and synthesising the literature-base through this lens and that of applied practitioners, end-users and then lastly blending subject matter expertise can promote a different initial focus that instead reduces barriers and finds more contextually driven solutions.

- While App-based technologies are highly adaptable, balancing expert opinion, end-user feedback and context-driven requirements with available resources is still a challenge. Within youth development settings, starting with the fundamental requirements, then utilising data-rich self-report methods, and attaching both these to achievable feedback loops and key return on investment markers is a realistic starting point. Gradually scaling approaches based on contextual reports and new technology, while maintaining the original integrity is recommended for sustainability.
- Technologically savvy athletes did not seem to suffer when first using the EPD App but added pressure and workload to coaches may have been apparent. The initial focus of athlete monitoring and injury surveillance should first consider educating and incentivising coaches on how both the process, and data outputs can be used to develop self-awareness and regulation strategies in their athletes. Once this is achieved, focus can shift to coaches themselves rolling out athlete monitoring and injury surveillance practices and educating their athletes as part of their normal workflows, not in addition to. To support athlete engagement alongside coach facilitation or in the absence of personalised coaching, gamification elements can be considered an additional consideration.
- Given end-user feedback in this setting may tend to follow a pattern, addressing key individual and personal perceptions and barriers may ultimately also alleviate some of the technological/system and environmental/infrastructure barriers, therefore fast-tracking development and implementation.
- Athlete monitoring and injury surveillance practices should be embedded within key organisational and pathway vision and mission objectives, then operationalised and appropriately incentivised throughout departments and key stakeholder roles and responsibilities for maximum effectiveness and sustainable diffusion.

5.3 Original Contribution to Knowledge

This thesis makes an original contribution to knowledge through:

- Synthesising the available athlete monitoring and injury surveillance literature base through the contextual lens of remote-athlete talent pathways and specifically English academy rugby union.
- Outlining how stages five and six of the TRIPP Framework and key implementation science components can be applied earlier in the sequence of sports injury prevention steps to improve remote-athlete data capture, whereby evidence is currently scarce. This approach was shown to reduce barriers to the Reach and Adoption of sporting innovations but not Implementation and Maintenance.
- Extending the utility of The Six-Step Intervention Development Process and RE-AIM Framework outside of injury prevention exercise program design to the development of future-focused, digital and mobile health applications and improved data capture mechanisms.
- Providing the first systematic account of the full-spectrum development, implementation and evaluation of an App-based athlete monitoring and injury surveillance system using evidence-based implementation science frameworks and tools.

5.4 Practical Implications and Potential Impact

The principle aim of this body of work was to produce research that could facilitate the reduction of barriers to remote-athlete monitoring and injury surveillance. In doing so it was hoped this research could enhance the currently limited capability of researchers and practitioners to successfully capture high-quality, longitudinal athlete monitoring and injury surveillance data in these settings. Considering the capture of this type of data is a fundamental and critical first step in evidence-based performance and safety decision-making, the practical implications and potential impact of this research warrants discussion.

Firstly, the synthesis of the current athlete monitoring and injury surveillance literature base through a contextual lens is unsurprisingly something researchers, and to a greater extent practitioner probably already do in different forms. This is however not particularly well illustrated within the literature. The focus still tends to be on broad consensus statements and conceptual models, fitting existing methods to contexts, rather than approaching athlete monitoring and injury surveillance firstly from a contextually driven standpoint. Research particularly still generally prescribes to replicating approaches from elite sport which may not be applicable, or even valid within other settings. The approach to knowledge synthesis in this thesis can therefore be used as a basis to be built upon, whereby researchers can encase their investigative deduction and reasoning expertise, by firstly taking guidance from both practitioners, and evidence from the context itself. A direct practical implication from this approach can be seen in the application of utilising stages five and six of the TRIPP Framework to better inform and re-imagine the capture of athlete monitoring and injury surveillance in stage one. Specifically, utilising stage five 'describe the intervention context to inform implementation strategy' before attempting any form of data collection or innovations development seems a plausible and practical suggestion. The impact of this can be seen in the reduction of barriers associated with Reach and Adoption and the identification of key focus areas of improvement in Chapter Four of this thesis.

Key Actions: **By starting with the context, then practical input, and finishing with rationalising solutions through peer-reviewed evidence, greater multi-disciplinary and multi-level collaboration is promoted. This leads to context-driven innovation solutions that will save time and resources in the future.**

The application of evidence-based implementation frameworks and tools such as the Six-Step Intervention Development Process and RE-AIM to developing, implementing and evaluating App-based sports innovations is a novel implication that has practical relevance. Given advances in technology and the growing digital and mobile health trend, evidence-based approaches to developing, implementing and evaluating these innovations are needed. The greater awareness, knowledge and application of relevant implementation science tools such as those featured in this thesis could also help accelerate a historically slow research to practice pipeline by aligning contextual evaluation with intervention efficacy right from the start.

Key Actions: **Using the Six-Step Intervention Development Process, together with the RE-AIM Framework, its associated Sports Setting Matrix and the uMARS tool can provide researchers and practitioners a framework in which to develop, implement and evaluate App-based athlete-monitoring and injury surveillance systems. This leads a more comprehensive development cycle that can be documented, iterated and improved upon.**

Stemming from the use of the above frameworks and tools, several considerations are apparent that may directly or indirectly influence practice. An interesting observation from the end-user feedback stage of the Six-Step Development Process was that feedback generally followed a specific timeline, whereby issues with the system/technology were first raised, then the socio-environment and finally individual and personal perceptions and knowledge. Understanding this flow and that many earlier issues could inevitably be linked to certain personal/individual factors disclosed later may influence how we introduce and educate coaches and athletes around athlete monitoring and injury surveillance innovations. Another observation was that regardless of overall use, academy rugby players perceived engaging with the EPD App improved their understanding and management of workload, wellbeing and injury. This has been previously observed in other athlete monitoring and injury surveillance research, especially with self-report methods and is based upon the cognitive and wellbeing benefits of 'self-reflection' and 'journaling'. This suggests there could be two fundamental benefits to sustained athlete monitoring and injury surveillance practices; 1) longitudinal data to inform decision-making and strategy representing a macro benefit, and 2) reflective practice and learning leading to micro developments in self-awareness and regulation strategies for athletes and coaches. Lastly, the considerable drop-off at the Implementation and Maintenance dimensions suggests these dimensions should be targeted when developing future-focused innovation and implementation strategies. This observation is supported within both the App-specific and sports setting research generally, however the mechanics of which may differ considerably depending on the context.

Key Actions: **Addressing personal/individual perceptions, values and knowledge relating to App-based athlete monitoring and injury surveillance practices first may help solve system/technology and socio-environmental factors in the future. Using athlete monitoring and injury surveillance as both a mechanism for macro and micro self-awareness and regulation developments could improve alignment and integration with other aspects of your program.**

Targeted planning for the Implementation and Maintenance dimensions of the RE-AIM Framework can improve innovations diffusion.

5.5 Future Directions

Improvements to the current research design should be considered in the future. The application of systematic and meta-analytic review types can strengthen the contextual literature review process. A more comprehensive and structured approach to qualitative data collection and analysis, and further scientific rigour generally within the research methods and statistical analysis sections can also be improved. This could involve key management, coaching and parental involvement within the RE-AIM evaluation components and the application of formal semi-structured interviews transcribed using thematic analysis techniques. Statistical methods that can better analyse and illustrate individual participant-use metrics than counts and proportions could also improve the sensitivity and rigour of findings.

A further consideration for future research design is that this type of research may be better suited to being principally led by an internal practitioner with appropriate scope of influence and action (e.g. Head of Sports Science) and/or internal senior management (e.g. Head of Pathways/Academy, Director of Rugby/Performance or Head Coach). This may better facilitate alignment and provide a quantifiable element of 'skin in the game' to the key strategic and operational decision-makers surrounding such research. The research team therefore becomes more a key advisory in guiding applied practitioner's and senior management's ideas and solutions to problems. While this research focused on multi-level and interdisciplinary collaboration, the project itself was still predominantly research led. The key project managers responsible for overseeing the research's day-to-day operations across the academy landscape were from research institutions. These project managers were ultimately responsible for the research and implementation, whereby other applied stakeholders were tasked with guiding and facilitating but with no measurable or specific responsibility. Flipping this dynamic and developing the appropriate infrastructure to support and incentivise may be key to future research and successfully targeting the sustained use of innovations.

Future implementation studies that look at repeating and re-evaluating the steps taken in this research could also be considered. Utilising implementation tools such as the RE-AIM Framework more readily to compare within and between studies, as well as using previous study designs and populations as control arms to test changes or validate new approaches in both innovations, and implementation design, could accelerate bridging the research to applied practice gap. Combining this with cross-departmental, academic institution and industry collaboration, while not without its complexities, could further enhance the evaluative datasets and their largescale application. With specific mention to the implementation of remote-athlete monitoring and injury surveillance, future research can consider better documenting and evaluating the bespoke development of new, and/or integration of existing technologies and innovations in this space. Targeting the Implementation and Maintenance dimensions as part of future research strategies is considered a logical next step in addressing the barriers to sustained use still present after this thesis's investigations.

Exploring more precise research questions relating to how the flow of feedback can be harnessed to better plan and educate surrounding sporting innovations could also be approached. A finding from this study lends itself to the hypothesis that feedback relating specifically to barriers of athlete monitoring and injury surveillance use, follows a path of first system/technology issues, then a lack of socio-environmental infrastructure and support, and finally to particular personal/individual perceptions, values and understanding. It could therefore be suggested that investigating and addressing personal/individual aspects may either be the source of barriers and/or have the potential to alter perceptions surrounding those faced in other areas. Investigating this hypothesis within the aforementioned implementation study designs could both improve understanding and implementation success.

Another more precise question is related to the impact of engaging in athlete monitoring and injury surveillance practices on self-awareness and regulation strategies. This study found that athletes on average perceived they improved both their knowledge and awareness in the areas of workload, wellbeing and injury prevention after engaging with the EPD App. It could therefore be hypothesised that this perceived increase in knowledge and awareness could help athletes ask more informed questions and make better self-care, preparation and organisational decisions. This would lead to greater actionable levels of self-regulation with far reaching performance lifestyle and injury prevention benefits. It also has the potential to provide a quantifiable link regarding the effectiveness and added value of athlete monitoring and injury surveillance on a micro level, whereby tracking athlete engagement, the development of athlete self-regulation and impact on injuries, illness and talent identification/development factors could all underlie key operational and organisational success factors. Changing the focus from a negative feedback loops (e.g. poor wellbeing, high workloads mean you're at risk) to a positive, learning feedback loop (e.g. why is my wellbeing poor and workloads high, and how can I regulate this for optimal performance and safety) may improve the widespread acceptability and engagement with athlete monitoring and injury surveillance that can lead to the macro benefits of a longitudinal dataset and evidence-based decision-making.

5.6 Thesis Conclusion

This thesis aimed to investigate reducing the barriers to remote-athlete monitoring and injury surveillance in English academy rugby union. In doing so, five novel research questions were addressed as part of this research.

As part of a contextually driven literature review process, it was identified that a smartphone application-based athlete monitoring and injury surveillance system with embedded self-report methods posed as the most viable solution to reducing barriers. The implications of this were that largescale data collection could be achieved remotely with only the ubiquitous use of a smartphone, rather than any other accessory hardware and personnel. This finding however raised the question as to how best approach developing, implementing and evaluating such innovations, and highlighted the lack of evidence-based literature in this area. Using the field of Implementation Science as a guide, a novel and evidence-based approach using the Six-Step Intervention Development Process, RE-AIM Framework and uMARS questionnaire documented and evaluated the bespoke development of the Elite Player Development (EPD) App and its implementation strategy. This detailed the first step-by-step approach and therefore provides a blueprint for future research and development. In evaluating the approach, both the EPD App and its associated implementation strategy were shown to reduce barriers to initial uptake and use, however, were unsuccessful at reducing barriers to sustained use. In doing this, the utility of employing participant-use and participant-perceived-quality metrics through the

RE-AIM Framework and uMARS was shown to systematically evaluate the EPD App and its implementation strategy. Key development and implementation considerations were that 1) starting with the context, then blending in practitioner and end-user opinion followed by expertise in the field and the existing literature-base can provide more contextually-driven solutions, 2) self-report methods, attached to automated collection and feedback loops provide a data-rich and simple starting point that can be scaled, 3) addressing coach's and other key middle-out facilitator's personal/individual values, perceptions and understanding, then linking this to the necessary incentives and supporting infrastructure should be considered foremost, and 4) multi-level alignment and embedding within organisational and operational objectives should be achieved before initiating athlete monitoring and injury surveillance practices. Exploring the self-regulation benefits of athlete monitoring and injury surveillance could improve this integration.

In conclusion, the findings from this research provide novel insights into approaching the reduction of barriers to remote-athlete monitoring and injury surveillance in academy rugby union and other remote-athlete settings. The impact of this research is possibly best explained through an analogy, whereby if you give a starving person some bread, they can feed themselves for a meal, however if you also give them the tools and knowledge to find ingredients and make bread themselves, there is a greater reach and sustained impact. Taking this one step further, if you can identify the key contextual factors facilitating the usage of these tools and engagement with knowledge, new and innovative types of bread to suit a range of tastes can also be created. If research shows us how to best 'iteratively' approach and think about designing, implementing and sustaining the use of athlete monitoring and injury surveillance practices, alongside the current provision of consensus statements and efficacy reporting, we will see a far greater impact on the availability of high-quality longitudinal data across sport and that of public health.

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7 APPENDICES

7.1 Academy Practitioner Workshop Survey

ENGLAND RUGBY

Elite Player Development App Feedback

UNIVERSITY OF BATH

LEEDS BECKETT UNIVERSITY

'Develop an engaging, realistic and achievable mechanism to capture, manage and present player information'.

	Most ---- Least
Does this App interest you?	3------2------1
Do you think this App could help your Academy in some way?	3------2------1
Given the 'right circumstances' could you see this App successfully collecting, managing and presenting player information at your Academy?	3------2------1
Would you be happy to trial this App?	YES / NO

If you could capture, manage and present 1-2 fundamental pieces of information on YOUR players what would they be?

1____

2____

If you could have support in 1-2 areas of your role what would they be?

1____

2____

What aspects of your work make you happy/do you enjoy?

____

____

____

____

7.2 Academy Briefing Document

THE TALENTED DEVELOPING PLAYER PROJECT:

INSIGHTS AND MECHANISMS FOR PLAYER WELFARE AND DEVELOPMENT

1 INTRODUCTION

England Rugby and Premiership Rugby Ltd, in collaboration with the University of Bath and Leeds Beckett University are undertaking a research project to investigate the multi-sport training, competition and life loads of developing rugby players (14-19yrs) and the relationship with injury and development. We would like to invite you to participate, help innovate and share in the findings.

2 THE PROJECT

The overall aim of the research project is to help develop and shape best practice for talented players in the professional player pathway. The project intends to do this through developing a comprehensive understanding of 'what youth rugby players actually do' and 'how it is effecting their welfare and development'. This will enable us to further understand the players' journey from a physical, psychosocial and injury perspective and ultimately best support player progression and success. A large-scale study will be used which will investigate the influence of player loads (playing, training and life) on injury and physical development. The study will be the most comprehensive of its kind in youth rugby to date and by working collaboratively with England Rugby's Regional Academies, the investigation is best placed to produce the information we all need and provide exceptional benefits for the participants involved.

2.1 BENEFITS TO PARTICIPATING

- Bespoke APP TECHNOLOGY and SOFTWARE
- COMPREHENSIVE INSIGHTS on ALL your developing players IN LESS TIME
- Additional STAFF and PROGRAM SUPPORT
- Active and acknowledged role in developing PLAYER WELFARE BEST PRACTICE

2.2 PARTICIPATION IN THE PROJECT

If your Club wishes to participate you will be requested to:

- Support and promote the use of a player monitoring App within your Academy OR provide timely and select player load-monitoring data in an acceptable format through your own capture means if they meet study validity and reliability requirements.
- Respond to 'injury alerts' and record 'time loss' injuries via Rugby Squad Medical.
- Complete a standardised physical testing battery with players, OR allow researchers access to collect physical testing data from your players at three time points throughout the year;
  - August – September
  - December – January
  - April – May
- Nominate a named Project Lead
- Provide evidence of formal agreement from your Club's Head of Performance and Academy Management Group to the aforementioned requests and to **participation from September 2017 – September 2020.**

1

2.3 PROJECT METHODS

Academies will be provided with dedicated support, training and help to embed the player load-monitoring App and Physical Testing Battery within their current practice.

Elite Player Development (EPD) App

The purpose-built EPD App will be provided to all participating Regional Academies, and will be used to remotely collect, manage and present player information.

Players will be expected to log into the App daily and alert staff of suspected injury, self-report their current fitness status, wellbeing and any activities they complete (pilot testing suggests this process takes approx 90sec). They will also be required to complete a weekly Life Loads and Performance Restrictions questionnaire (approx 180sec). The Life Loads and Performance Restrictions questionnaires will only be available Sunday and Monday of each week.

Academy Staff will be expected to support and promote the use of this technology and will have access to the following player information and analysis features to support their program:

- Capture Player Fitness Status, Wellness, Life Loads, Performance Restrictions and Activity data.
- Export data into easy to manage Excel files
- View Team and Group Player Load Analytics (Daily, 7 day and 28 day rolling ave)
- View Life Load, Activity and Wellness Graphs
- Receive and manage Injury Alerts
- View Player Status and Compliancy Log

Physical Testing Battery

A physical testing battery has been developed and agreed with England Rugby and Academy Strength and Conditioning Staff (26th April 2017 *Academy Strength and Conditioning Forum*). The physical testing battery will be completed at three time points throughout the year (August – September, December – January, April – May). The physical testing battery can be completed in full / part by the research team at your regional academy, OR by Academy staff within your club, if the protocols already form part of current / future practice. The testing battery will consist of:

Anthropometric measures: Height and Body Mass

Physical Maturation Status: Player Height and estimated Parent Height

Body Composition: Bioelectrical impedance analysis

Strength: Isometric mid thigh-pull via a modified back dynamometer *(modified back dynamometer can be provided for the duration of the project if required)*

Lower-body Power: Countermovement jump height on a force platform or Optojump

Sprint Speed: Maximum velocity on an outdoor 3G or 4G surface (10, 20, 30 and 40m sprint splits)

Aerobic Capacity: Yo-Yo IRTL-1

3 NEXT STEPS

A. Consult this Document and discuss with your Club staff.

B. Arrange a formal Project and App briefing visit between June – September 2017, by contacting Mark Atkinson (m.atkinson@bath.ac.uk) from Monday 12th June 2017.

C. Decide on participation.

D. IF YES - Begin on-boarding and operations procedures by September 2017

4 CONTACTS

This document has been developed and approved by the following;

Don Barrell (Regional Academy Manager – England Rugby)

Mark Bennett (Head of Sports Science and Medicine – England Rugby)

Corin Palmer (Premiership Rugby Ltd**)**

Mark Atkinson (Project Lead – University of Bath) E: m.atkinson@bath.ac.uk P: [redacted]

If you have any further queries please contact Mark Atkinson who can answer/direct your query.

5 APPENDICES

Please find attached further information on the Elite Player Development App

Talented Developing Player Project

Club Agreement Sign Off

____ has agreed to participate in the Talented Developing Player Project (TDP) and accepts the project requests in SECTION 2.2 of the Club Briefing Document.

Academy Management Group Representative

NAME: ____

POSITION HELD AT CLUB: ____

DATE: ____

SIGNATURE: ____

Club Performance Manager / Senior Team Representative

NAME: ____

POSITION HELD AT CLUB: ____

DATE: ____

SIGNATURE: ____

Nominated Club Based Project Lead

NAME: ____

POSITION HELD AT CLUB: ____

DATE: ____

SIGNATURE: ____

7.3 Player Consent Example

TDP Project Player Consent (2017 - 2021)

Page 1: Page 1

PLAYER INFORMATION

The Talented Developing Player (TDP) Project: Player Loads, Physical Qualities and relationship to Injury and Development

Supported by: Rugby Football Union and Premiership Rugby Ltd

Principal Investigators:

Prof. Keith Stokes: Email: K.Stokes@bath.ac.uk;

Tel: 01225 384190

Dr. Ben Jones: B.Jones@leedsbeckett.ac.uk

Tel: 01138 12 4009

Other investigators:

Dr. Sean Williams: Email: S.Williams@bath.ac.uk

Mark Atkinson: Email: M.Atkinson@bath.ac.uk

Padraic Phibbs: Email: P.Phibbs@leedsbeckett.ac.uk

Dale Read: Email: D.Read@leedsbeckett.ac.uk

We are asking you to take part in a study of player loads, development rates and injury occurrence in developing rugby players, supported by the Rugby Football Union. 'Player loads' refer to the physical demands associated with training and competing in sports (i.e., how long and hard you have exercised for), as well as the mental demands of school and other life stresses (e.g., not getting enough sleep). Before deciding whether you want to take part, you should know why we are doing the study and how it will affect you. Take time to the read the information carefully. If there is anything that you do not understand, please speak to a member of your rugby programme team (coach/doctor/physiotherapist) or contact us for further information. When you have read and understood the information, if you wish to be in the study, you will be asked to sign a Player Consent Form.

Section 1: Background to the study

Injuries are an unfortunate part of sport for youth athletes, and rugby is no different. However, there are some injuries that may be preventable through ensuring that your levels of fatigue and fitness are appropriate, and this may be especially important in young and developing athletes. It has been shown in senior professional rugby players that the physical loads associated with training and playing matches are linked to how likely it is that they get injured. Other types of 'load', like the stress of schoolwork, might also change your injury risk. These 'player loads' have been difficult to monitor in youth athletes, but smartphone applications (apps) may now allow us to collect this

information more easily. Therefore, we have designed a bespoke smartphone App and fitness testing protocol that will enable us to assess the relationships between your 'player loads', injury and development.

Section 2: What does the study involve?

Your academy staff will explain how to install and use the app. The researchers will also be on hand via email to provide assistance. Once your consent is received you will be emailed a link to register for the app. For the rest of the study, we will ask you to use the app to:

- Record the duration and intensity of all training and matches that you participate in (for all sports and general activity) (takes about 30 seconds).
- Answer a wellness questionnaire each morning (takes about 30 seconds).
- Report any injuries that you have sustained.
- Complete two weekly questionnaires; one relates to your current 'life loads' (e.g. how well you are managing at school), and the other relates to any performance restriction problems you may have (takes about 180 seconds).

You will also be asked to complete a physical testing battery designed to assess physical characteristics (height, weight, body mass, body composition), athletic qualities (strength, power, speed and aerobic capacity) and physical maturation (parent/player height). Players will complete these tests three times a year as part of their normal training within their Academy. Information will be analysed by researchers at the University of Bath and Leeds Beckett University.

Section 3. Whom are we asking to take part?

Players in U15-U18 squads in regional rugby academies.

Section 4. Do I have to take part?

It is up to you whether you take part in the study. You do not have to take part but the more players who take part, the more we will find out about the number of injuries that occur. If you want to take part, you must sign a consent form say that you have read this information and you agree to be included in the study. You can withdraw from the study by contacting us at any time without giving a reason.

Section 5. What do I have to do?

If you choose to take part in the study you will have to first complete the consent form on the next page. Once the researchers receive your consent you will be sent an email with an invitation to register and download the App (you can also access via your

desktop computer). You will then go about your normal training and playing while recording the information stated above to your App (you will receive a handy SMS reminder to keep you up to date). You will also complete the aforementioned physical testing battery as part of your normal training three times a year.

Section 6. Are there any risks from taking part?

There are no additional risks associated with taking part in this study, beyond those involved in your normal rugby activities.

Section 7. How can I withdraw from the project?

If you wish to withdraw from the project, you can inform one of the above-identified researchers or your coach by email, telephone or in person. You can withdraw from the project at any point without providing reasons for doing so and without any inconvenience. If, for any reason, you wish to withdraw your data please do so *by June 1st of EACH Academy season throughout the study*. This is so we can produce 'annual reports' and therefore *any information not withdrawn by this time EACH YEAR will be included in that season's annual report*. As all data are anonymised, your individual results will not be identifiable in any way.

Section 8. Will information about me be kept confidential?

The Data Protection Act says that we must have your permission to collect information about you during this study. All information collected is stored using a code number rather than your name.

Section 9. What will happen to the information from the study?

The information will be analysed by researchers at the University of Bath and Leeds Beckett University and used to generate reports for England Rugby, Regional Academies and as part of Academic research to further player development and welfare best practice. No personal references will be made in any report. Data and insights will be shared with coaches to better understand and optimise your development and safety. The information already forms part of existing practice however it is important to note that it is NOT the responsibility of the research team to determine how coaches use your information as part of their Academy practice.

Page 2: CONSENT

PLAYER CONSENT

I have read and understand the information about this study and I have had a chance to ask questions.

I agree to take part in the study, and that the information collected will be used only for research purposes and in a report to my academy by the Researcher's. I understand that it is NOT the responsibility of the Researcher's to control how the Academy uses my information within existing Academy practice.

I understand that I can withdraw from this study at any point from now until ***June 1st of EACH YEAR*** without being asked why. Each year you choose to remain involved your information will be used for that year's Annual Report and published research.

1. PLAYER NAME

1.a PLAYER D.O.B

Dates need to be in the format 'DD/MM/YYYY', for example 27/03/1980.

(dd/mm/yyyy)

1.b PLAYER'S ACADEMY

- Bath Rugby
- Bristol Rugby
- Exeter Chiefs
- Gloucester Rugby
- Harlequins
- Leicester Tigers
- London Irish
- Newcastle Falcons
- Northampton Saints
- Sale Sharks
- Saracens
- Wasps
- Worcester Warriors
- Yorkshire Carnegie

1.c PLAYER SQUAD

- U15
- U16
- U18

1.d PLAYER EMAIL (This email will be used for your App account)

1.e PLAYER MOBILE NUMBER (this is so you can keep up to date with EPG App)

1.f PLEASE TICK BOX IF YOU ARE HAPPY TO PROVIDE YOUR CONSENT TO BE APART OF THE TDP PROJECT

- I CONSENT
- I DO NOT CONSENT

1.f.i TODAY'S DATE

Dates need to be in the format 'DD/MM/YYYY', for example 27/03/1980.

(dd/mm/yyyy)

2. IN THE EVENT THAT YOU NO LONGER WISH TO PARTICIPATE IN THE STUDY

- I AM HAPPY for any data collected prior to be used by researchers
- I am NOT HAPPY for data collected to be used by researchers but accept Section 7

Page 3: TDP Project Consent Complete

Thank you for participating in the Talented Developing Player (TDP) Project. The information you provide will help to further your development and that of future players. Good luck from the TDP Research Team!

TDP Project Parental Consent (2017 - 2021)

Page 1: Page 1

PARENT INFORMATION SHEET

The Talented Developing Player (TDP) Project: Player Loads, Physical Qualities and relationship to Injury and Development

Supported by: The Rugby Football Union (RFU) and Premiership Rugby Ltd (PRL)

Principal Investigators:

Prof. Keith Stokes: Email: K.Stokes@bath.ac.uk;

Tel: 01225 384190

Dr. Ben Jones: B.Jones@leedsbeckett.ac.uk

Tel: 01138 12 4009

Other investigators:

Dr. Sean Williams: Email: S.Williams@bath.ac.uk

Mark Atkinson: Email: M.Atkinson@bath.ac.uk

Padraic Phibbs: Email: P.Phibbs@leedsbeckett.ac.uk

Dale Read: Email: D.Read@leedsbeckett.ac.uk

We are asking your child to take part in a study of player loads, development rates and injury occurrence in developing rugby players, supported by the RFU and PRL. 'Player loads' refer to the physical demands associated with training and competing in sports (i.e., how long and hard you have exercised for), as well as the mental demands of school and other life stresses (e.g., not getting enough sleep). Before deciding whether you are happy for your child to take part, you should know why we are doing the study and how it will affect them. Take time to the read the information carefully. If there is anything that you do not understand, please speak to a member of your rugby programme team (coach/doctor/physiotherapist) or contact us for further information. When you have read and understood the information, if you wish to be in the study, you will be asked to sign a Player Consent Form.

Section 1. Background to the study

Injuries are an unfortunate part of sport for youth athletes, and rugby is no different. However, there are some injuries that may be preventable through ensuring that your levels of fatigue and fitness are appropriate, and this may be especially important in young and developing athletes. It has been shown in senior professional rugby players that the physical loads associated with training and playing matches are linked to how likely it is that they get injured. Other types of 'load', like the stress of schoolwork, might also change your injury risk. These 'player loads' have been difficult to monitor in youth athletes, but smartphone applications (apps) may now allow us to collect this

information more easily. Therefore, we have designed a bespoke smartphone App and fitness testing protocol that will enable us to assess the relationships between your 'player loads', injury and development.

Section 2. What does the study involve?

Your child's academy staff will explain how to install and use the app. The researchers will also be on hand via email to provide assistance. Once both your and your child's consent is received your child will be emailed a link to register for the app. For the rest of the study, we will ask your child to use the app to:

- Record the duration and intensity of all training and matches that you participate in (for all sports and general activity) (approx 30s).
- Answer a wellness questionnaire each morning (approx 30s).
- Report any injuries that you have sustained.
- Complete two weekly questionnaires; one relates to your current 'life loads' (e.g. how well you are managing at school), and the other relates to any performance restriction problems you may have (approx 180s).

Your child will also be asked to complete a physical testing battery designed to assess physical characteristics (height, weight, body mass, body composition), athletic qualities (strength, power, speed and aerobic capacity) and physical maturation (parent/player height). Players will complete these tests three times a year as part of their normal training within their Academy. Information will be analysed by researchers at the University of Bath and Leeds Beckett University.

Section 3. Whom are we asking to take part?

Players in U15-U18 squads in regional rugby academies.

Section 4. Does your child have to take part?

It is up to you whether your child takes part in the study. You do not have to take part but the more players who take part, the more we will find out about the number of injuries that occur and being able to better safeguard against this. If you're happy for your child to take part, you must sign a consent form saying that you have read this information and you agree for them to be included in the study. Your child can withdraw from the study by contacting us at any time without giving a reason.

Section 5. What do I and my child have to do?

If you choose to take part in the study you will have to first complete the consent form on the next page. Your child will also be sent the same form. Only once the researchers

receive BOTH parent and child completed forms will your child be emailed a registerstration link to the App. Your child will then go about their normal training and playing while recording the information stated above to their App. They will receive a handy SMS reminder to keep them up to date and so your child's Academy staff can efficently manage adherence. They will also complete the aforementioned physical testing battery as part of their normal training three times a year.

Section 6. Are there any risks from taking part?

There are no additional risks associated with taking part in this study, beyond those involved in your normal rugby activities.

Section 7. How can I withdraw from the project?

If you wish to withdraw your child from the project, you can inform one of the above-identified researchers or your coach by email, telephone or in person. Your child can withdraw from the project at any point without providing reasons for doing so and without any inconvenience. If, for any reason, you wish to withdraw your child's data please do so *by June 1st of EACH Academy season throughout the study*. This is so we can produce 'annual reports' and therefore *any information not withdrawn by this time EACH YEAR will be included in that season's annual report*. As all data are anonymised, your individual results will not be identifiable in any way.

Section 8. Will information about your child be kept confidential?

The Data Protection Act says that we must have your and your child's permission (if U18 at time of consent) to collect information about your child during this study. All information collected is stored using a code number rather than their name.

Section 9. What will happen to the information from the study?

The information will be analysed by researchers at the University of Bath and Leeds Beckett University and used to generate reports for the RFU, Regional Academies and as part of Academic research to further player development and welfare best practice. No personal references will be made in any report. Data and insights will be shared with coaches to better understand and optimise your child's development and safety. The information already forms part of existing practice however it is important to note that it is NOT the responsibility of the research team to determine how coaches use information as part of their Academy practice.

Page 2: CONSENT

PARENTAL CONSENT

I have read and understand the information about this study and I have had a chance to ask questions.

I agree to allow my child to take part in the study, and that the information collected about my child will be used only for research purposes and in a report to my child's academy by the Researcher's. I understand that it is NOT the responsibility of the Researcher's to control how the Academy uses my child's information within existing Academy practice.

I understand that I can withdraw from this study at any point from now until ***June 1st of EACH YEAR*** without being asked why. Each year you choose to remain involved your information will be used for that year's Annual Report and published research.

1. PARENT/GUARDIAN NAME

1.a CHILD'S NAME

1.b CHILD'S EMAIL (This email will be used for your child's App account)

1.c CHILD'S ACADEMY

- Bath Rugby
- Bristol Rugby
- Exeter Chiefs
- Gloucester Rugby
- Harlequins
- Leicester Tigers
- London Irish
- Newcastle Falcons
- Northampton Saints
- Sale Sharks
- Saracens
- Wasps
- Worcester Warriors
- Yorkshire Carnegie

1.d PLEASE TICK BOX IF YOU ARE HAPPY TO PROVIDE CONSENT FOR YOUR CHILD TO BE APART OF THE TDP PROJECT

- I CONSENT
- I DO NOT CONSENT

1.d.i TODAY'S DATE

Dates need to be in the format 'DD/MM/YYYY', for example 27/03/1980.

(dd/mm/yyyy)

2. IN THE EVENT THAT YOU NO LONGER WISH FOR YOU CHILD TO PARTICIPATE IN THE STUDY

- I AM HAPPY for any data collected prior to be used by researchers
- I am NOT HAPPY for data collected to be used by researchers but accept Section 7

Page 3: TDP Project Consent Complete

Thank you for allowing your child to participate in the Talented Developing Player (TDP) Project. The information your child provides will help to not only further their development but that of future players as well. Good luck to you and your child from the TDP Research Team!

7.4 EPD App Registration and User Guides

Elite Player Development (EPD) App User Guide

STEP 1: CONSENT LINK

- Players and Parents will be emailed two consent links by their Academy.

STEP 2: COMPLETE CONSENT SURVEY

- Players and Parents check you have answered ALL questions before submitting.
- If you have not completed BOTH player and parent consents you cannot go to STEP 3.

STEP 3: RECEIVE APP 'INVITATION EMAIL' AND 'CREATE PASSWORD'

- Players will receive two emails from 'RFU Elite Player Development'.
  I. First email will ask players to 'verify' their account by clicking on a link.
  II. Second email will ask players click a link to 'create a password'

NOTE: *If you have not received an invitation email in 2-days please check the following:*

I. You have completed BOTH player and parent consents
II. Your junk mail or sec5urity filters on your email account (school and business emails tend to have strong filters)
III. You provided the correct/same email address on your consents
IV. If you STILL haven't received an invitation email please alert your Academy.

STEP 4: DOWNLOAD EPD APP OR ACCESS VIA THE WEBSITE

- Go to your device's App store and search 'EPD' or 'Elite Player Development'
- Download the EPD (MyLife Digital) App with the England Rugby red rose.
- You can access the website version via https://epd.consentric.io/Login

STEP 5: LOGIN

- Please use your 'email address' and newly created 'password' to login to the App/website.
- If you have forgotten your password use the link below the login information on App/website.
- If you cannot login/view the App check you have updated to the latest browser/operating software version. If problems persist contact your Academy.

USING YOUR EPD APP

1. **Update Your Profile Video: https://www.youtube.com/watch?v=Shwx6_Mz7eU**
2. **Current Fitness/Injury Status and Wellbeing Video: https://www.youtube.com/watch?v=8IFrKX65AqE**
3. **Add and Activity or Rest Day Video: https://www.youtube.com/watch?v=_EYTrVmD1Rk**
4. **Fill in 2 WEEKLY surveys (Oslo and Life Loads) which are open Sunday and Monday each week.**
5. **Please ask your Academy for further support. Your information will be used by your Academy and University of Bath Researchers to develop your individual talent and those of the future!**

Overview of Elite Player Development roles and functions

The role that you have been set-up with on the Elite Player Development App controls your ability to access certain features. The table below provides a brief summary of these combinations.

	Club Admin	Physio	Player
Add/remove club admins, physios and players	✓		
View player profiles	✓	✓	✓
View number of outstanding reports	✓	✓	✓ (Player only)
View player fitness status	✓	✓	✓ (Player only)
View aggregate survey responses	✓	✓	
Update player profile			✓
Complete surveys (fitness status, wellbeing, life loads and Oslo trauma)			✓
Record activities			✓
View details of activities			✓
View player load graph			✓
Receive injury alerts			
View load graph of activities for the club and squads	✓	✓	
Export detailed player survey responses	Future software release		

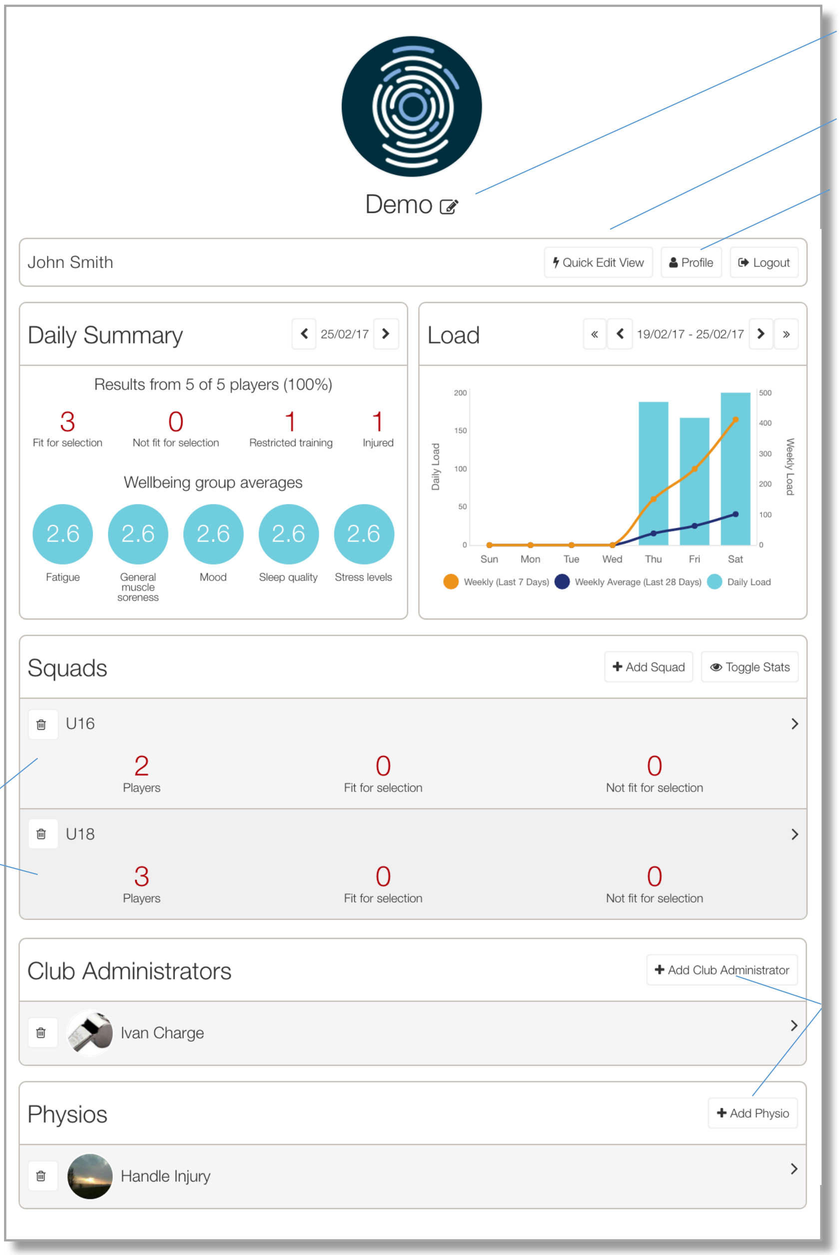
Note – an email address can only be associated with role

Admin - Club Dashboard

Edit club name and image

Hide Daily Summary and Load boxes

Access Admin Profile details



Daily Summary
Summary results from all players in club for a specific day

Wellness
Scale 1-5 where 1 is good and 5 is poor

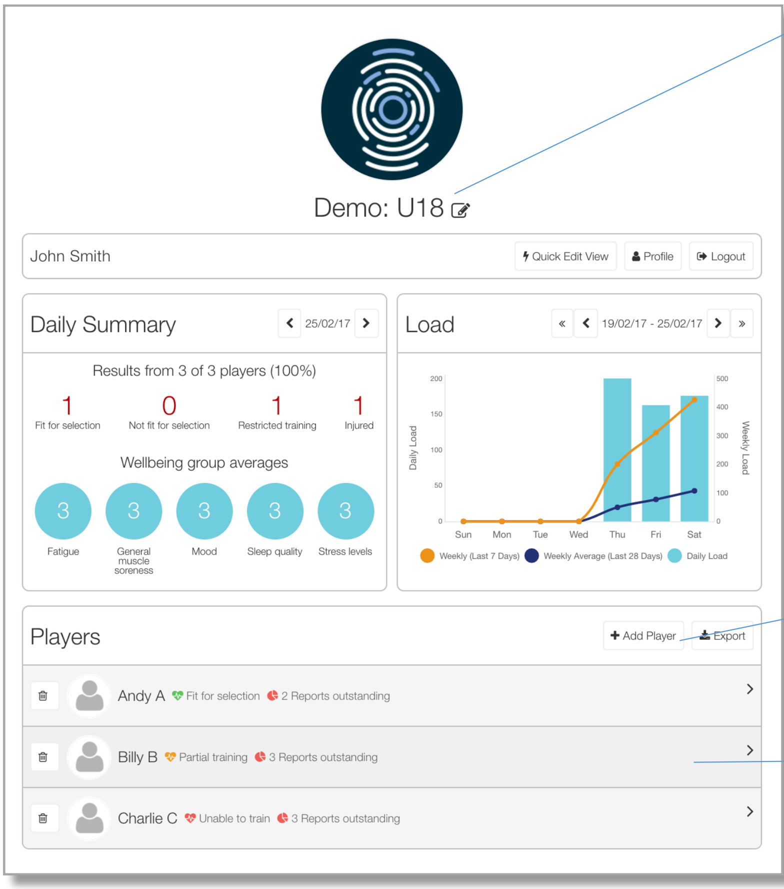
Squads
Summary squad details.

Click a squad to access squad dashboard.

Load
Daily Load
Average of all players who recorded an activity on that day
Weekly
Total load for last 7 days divided by number of players in squad
Weekly average
Total load for last 28 days days divided by number of players in squad divided by 4

Add additional Club Admins and Physios

Admin - Squad View and adding a player



Edit squad name

Daily Summary
Note – summary details are now for squad rather than club

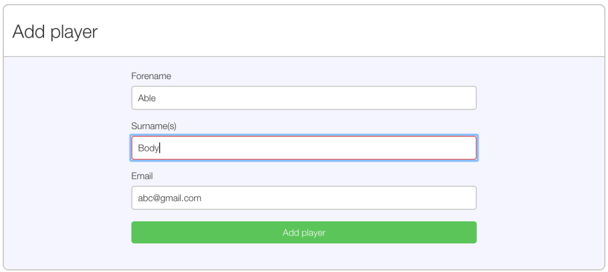
Add additional player

Players
1. Player fitness status and survey completion displayed.
2. Fitness status is for when the player last completed a survey.
3. If the player hasn't completed a survey in the last 7 days the fitness status will be shown as unknown.

Click on a player to view their profile

Add a player

1. Enter basic player information and click add player.
2. The player will then receive an email with a registration invitation
3. Once registered, the player can then add their DOB and mobile number to their profile



Troubleshooting

Issue	Questions and things to check	Workaround
My player/physio hasn't received their invite	1. Check the email address on the player profle is correct 2. Ask the player to check their spam folder	1. Delete the player you created. Resend email to a different email address
My player/physio hasn't received their password reset email	1. Ask the player to check their spam folder	1. Delete the player you created. Resend email to a different email address
My player/physio can't login	1. Do they have wifi or mobile connection? E.g. can they successfully browse to another website? 2. Can they see the login page with England Rose? 3. What error message do they receive? 4. Check their player profile to ensure they are using the correct email account to login 5. Can other people login or is it just this one player? 6. What device and browser are they using	1. If they are using the correct email account to login and the error message is 'Wrong email or password', use the 'forgotten password link' on login page to reset password 2. Please speak to Mark Atkinson on 07925 245 588 if this doesn't resolve the issue

Information to help with MLD investigation

1. When was the problem first experienced? What was the
2. Which users are effected? e.g. one player, all player, just physios
3. What device and browser is the error being seen on? e.g Windows10/Chrome
4. Has anything changed since the last successful login?
5. If possible, a screenshot from the device will help diagnose the problem

Player Frequently Asked Questions

https://epd.consentric.io/FAQ

I can't login to the app
If you see an error message that you have the wrong username or password, please use the 'reset your password' link on the login page. If this isn't successful, please contact your squad admin and ask them to check the email that is used in your profile.

What information can I record in the app?
The app allows you to record your contact details, injury status, availability for selection, wellbeing and activities.

Where can I enter and edit my personal details?
Your profile page can be accessed from the homepage (to the right of your name) or drop down menu. All fields on this page can be edited.

How is the load calculated for my activities?
Load is calculated by multiplying the duration and intensity of the activity. For example, a 60 minute gym session with an intensity of 5 would result in a load of 300.

How often do I need to complete the surveys?
The current status, wellbeing and activities need to be completed daily. The Life loads and Oslo Trauma need to be completed weekly.

How long do I have to complete the surveys?
All surveys expire after two days. The weekly surveys (Life Loads and Oslo Trauma) must be completed weekly.

Can I see the surveys that need to be completed in the app?
Yes. When you login to the app the alerts section will show you any surveys that are due for completion.

What happens if I close the app or lose connection half way through a survey?
The app remembers your progress through the survey and will return you to the appropriate section next time you enter that survey

Who can see my data and what is it used for?
This information is used to:

- produce reports, surveys and updates that help your academy, medical professionals or the RFU with player development.
- produce anonymised medical research, surveys and reports.

Who should I contact for support?
Please contact your squad admin with any queries.

7.5 Academy and Player Education Workshops

DEPARTMENT FOR HEALTH
Sport, Health and Exercise Science

TALENTED DEVELOPING PLAYER PROJECT

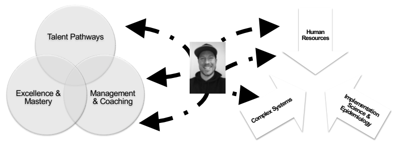
Regional Academy Workshop

Presented by Mark Atkinson

CONTACT Mr. Mark Atkinson m.atkinson@bath.ac.uk

MARK ATKINSON

'Performance Specialist' interested in sports and entertainment;



Raw Data from Elite Player Development App

CONTACT Mr. Mark Atkinson m.atkinson@bath.ac.uk

2

Why Talent Pathway Research…

As we let one light shine, we unconsciously give other people permission to do the same…

– Marianne Williamson

(or Coach Carter…)

Talent Pathways are about a 'positive compounding legacy'

The emergence of one talented individual, can inspire a lifetime of success, and that of others!

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3

I'll SHOW and you TELL

1. **'SHOW' ELITE PLAYER DEVELOPMENT APP →** 'TELL' US HOW YOU CAN USE THIS
2. **'SHOW' HOW TO EXPORT & FILTER DATA →** 'TELL' US WHATS INTERESTING?
3. **'SHOW' HOW TO USE ATHLETE REPORTS →** 'TELL' US WHATS USEFUL?
4. **'SHOW' IMPLEMENTATION PRINCIPLES →** 'TELL' US ABOUT YOUR PROGRAM

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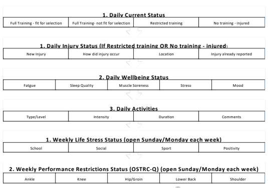
4

1. 'SHOW' ELITE PLAYER DEVELOPMENT APP

1. WHAT? Elite Player Development (EPD) App is a data capture and compliance system.
2. HOW? 'Players' input data, 'Administrators' can view compliance and export data for analysis.
3. Players are reminded via SMS if they do not complete a status by 1100 each day.
4. Key Features
   a) Login & Reset Password
   b) Overall, Squad and Individual Compliance Logs
   c) Squad Summaries (Current Status, Load, Wellbeing)
   d) Survey Visualisations and Data Exports



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5

Competition

EVERYONE LOG OUT

FIND HOW MANY U16 PLAYERS COMPLETED SURVEYS ON THE…

'DATE'

GO!

Raw Data from Elite Player Development App

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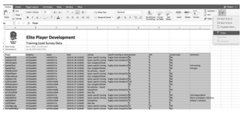
6

2. 'SHOW' HOW TO EXPORT & FILTER DATA

1. Filters
   1. What training has player A done this week?
   2. Who is injured this week?
   3. Who is not coping with school?

Anything else…?



Raw Data from Elite Player Development App

7

3. 'SHOW' HOW TO USE ATHLETE REPORTS

1. TDP Weekly Squad Report
   a) Who has completed the most training minutes?
   b) Who has completed the most competitive games in total?
   c) Anything else?

2. TDP Individual Player Report
   a) Have any players reported injuries?
   b) Are any players experiencing a load imbalance (<0.8 and/or >1.5).
   c) Does this mean anything?
   d) What could we do to mitigate this?

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8

4. 'SHOW' IMPLEMENTATION PRINCIPLES

'the scientific study of methods to promote the systematic uptake of evidence-based approaches (research) into practice' (Bauer, Damschroder et al. 2015).

Group Task: WHAT 'CAN' YOU MONITOR?

a) U16 Playing Squad
b) Contracted Player Transitioning into Professional Rugby

Raw Data from Elite Player Development App

9

4. 'SHOW' IMPLEMENTATION PRINCIPLES

Group Task: WHAT SHOULD YOU MONITOR?

a) U16 Playing Squad
b) Contracted Player Transitioning into Professional Rugby

1. *What's the Purpose, Incentives and KPI?*
2. *Is it Essential?*
3. *What is our Feedback Loop?*
4. *Evaluating Barriers (Personal, Socio-Contextual, System)?*
5. *Implementation Strategy*

Raw Data from Elite Player Development App

10

I'll SHOW and you TELL

1. **'SHOW' ELITE PLAYER DEVELOPMENT APP** → 'TELL' US HOW YOU CAN USE THIS
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Raw Data from Elite Player Development App

11

Follow Up

Develop an Implementation Strategy for the EPD App applying these principles;

1. *What's the Purpose, Incentives and KPI's from EPD App Data?*
2. *Is it Essential?*
3. *What is our Feedback Loop?*
4. *Evaluating Barriers (Personal, Socio-Contextual, System)?*
5. *Implementation Strategy, Trial and Review*

Please feel free to contact me with any questions/ideas

m.atkinson@bath.ac.uk
07925245588

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12

Monitoring Cycle

UNIVERSITY OF BATH

- Player Performance Stories
  - AIM: Use players own App data to drive learning, self management and compliance while providing coaches with insights into playing-training-wellbeing habits.
  - Players describing/reflecting/reviewing their own playing-training-wellbeing habits.
  - Can be presented to everyone or small custom groups (positions).
  - Can be short weekly snippets as part of training or longer form reviews at camps/monthly.
  - Questions/particular formats driven by what coaches want to know about players (training/playing habits outside of Academy sessions) and skills they want players to learn (e.g. load-stress management strategies).
- Compliance/Commitment Leaderboards
  - Monthly compliance/commitment leaderboards (your compliance dictates your commitment)?
  - Use groups to stimulate competition.
- Academy Player Data Insights & Feedback Loops

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13

Elite Player Development App

UNIVERSITY OF BATH

1. Daily Current Status

Full Training - fit for selection	Full Training- not fit for selection	Restricted training	No training - injured

1. Daily Injury Status (If Restricted training OR No training - injured)

New Injury	How did injury occur	Location	Injury already reported

2. Daily Wellbeing Status

Fatgue	Sleep Quality	Muscle Soreness	Stress	Mood

3. Daily Activities

Type/Level	Intensity	Duration	Comments

1. Weekly Life Stress Status (open Sunday/Monday each week)

School	Social	Sport	Positivity

2. Weekly Performance Restrictions Status (OSTRC-Q) (open Sunday/Monday each week)

Ankle	Knee	Hip/Groin	Lower Back	Shoulder

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14

6 out of 6 = RECONFIRMATION & FOLLOW UP

UNIVERSITY OF BATH

Use data to inform best practice in YOUR environment

LEARN: 🤓

- Implementation Science Principles
- Navigate, Find and Export Data from EPD App
- Import and Visualise Data through the TDP Monitoring Template

EXPLORE: 🧐

Strategies to develop 'buy in' and compliance

DEVELOP: 🏆

- Understanding of 'essentials' (what matters to you and your roles)
- Purpose-made feedback loops

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15

FAST 5

UNIVERSITY OF BATH

1. 'Experience-based' practice (tried, but not tested) tells us there is currently a huge COMPETING energy, fatigue and stress cost to being an English rugby academy athlete (and practitioner…)
2. Little 'tested' evidence within English academy rugby players to support this…
   1. Single academy training and match demands (Read, D. B., et al. (2017)
   2. Single academy training and match habits (Weakley, J. J. et al. 2017, Phibbs, P. J., et al. 2018)
   3. Multiple academy training and match habits + injury (Palmer-Green, Stokes et al. 2013)
3. BARRIERS! Remote-athletes, multi-stakeholders, limited resources and alignment…
4. 'Evidence-based' practice (tried and tested) tells us that 'better-informed' planning and management of development stimuli improves our academy practitioner role outcomes (Windt and Gabbett 2017)
   1. Goal Orientated (SMARTER)
   2. Balanced (Exposure vs Adaptation)
   3. Ecologically Flexible (Can adapt to changing environment)
5. Implementing high-quality data systems is the first step… (Kipsaina, Ozanne-Smith et al. 2015, Robertson, Bartlett et al. 2017)

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16

TDP Project Academy Workshop Series

UNIVERSITY OF BATH

ITINERARY

1. **Context (DB – RE) (10mins)**
   - Aim → Importance of data and link to RFU/Academies Objectives/Strategies.
2. **Interactive EPD App Walk Through (MA) (15mins)**
   - Aim → Navigate, Find and Export Data
3. **Interactive TDP Monitoring Template Walk Through (MA – SW) (30mins)**
   - Aim → Show data visualization/use examples and promote questions
   - TDP Monitoring Template Tutorial https://www.youtube.com/watch?v=IXh0S50FI1A

BREAK 10-15mins

4. **Group Tasks/Discussions (ALL) (30-45mins)**
   - **Q:** How can data be best used?
   - ***Actions:*** Establish Daily, Weekly, Monthly, Long Term Feedback Loop examples.
   - **Q:** What strategies can we use to efficiently maintain compliance?
   - ***Actions:*** A list of strategies Academies are happy to begin implementing.
   - **SWOT** Analysis of Project/General Discussion.
5. **Summary and Follow Up (15mins)**
   - What we will do now.
   - When will we next meet to discuss?

TIME = 80 – 100mins

Allow 2hrs

Attending:
Don Barrell (DB)
Robin Eager (RE)
Matt Cross (MC)
Mark Atkinson (MA) University of Bath
Sean Williams (SW) University of Bath
Keith Stokes (KS) RFU/University of Bath

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17

Session Overview

UNIVERSITY OF BATH

1. **WARM UP & OBJECTIVES**	15mins (1539-1554)
2. **ACTIVATION BREAK** → Head in the game	5mins (1555-1600)
3. **TECHNICAL TRAINING** → Interactive App – Monitoring Template walkthroughs	30mins (1600-1630)
4. **CONFIRMATION BREAK** → Are we on script?	5mins (1630-1635)
5. **TACTICAL TRAINING** → Essentials – Purpose & Incentive – Feedback Loops	30mins (1635-1705)
6. **STRATEGY RECONFIRMATION & FOLLOW UP**	5mins (1705-1710)

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18

What floats my boat…

As we let one light shine, we unconsciously give other people permission to do the same…

– Marianne Williamson

(or Coach Carter…)

19

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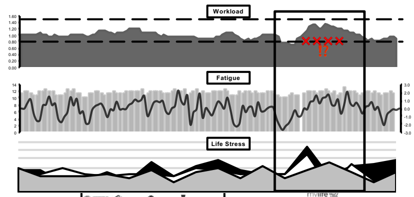
2017/18 Season Data Examples



20

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Follow Up

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21

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Elite Player Development App

Pro Athlete Skills Series
EPISODE 1:
'Using your Load Graph for better Development Recovery and Readiness to Perform'

mylife digital

What is *Load*?

Load = your combined physical activity ***intensity*** and ***duration.***

Example: **60mins** of school rugby training x 'Hard' Intensity Rating **(=5)**

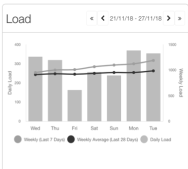
= Session Load of **300 (60x5)**

Professional Athletes and Elite Performers use this to calculate *'their work performed'*.

***Coaches* use this information to plan weekly training.**

Monitoring your 'work performed' can help improve your Performance, Development and Recovery!

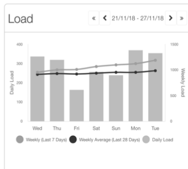
What's on *my* Load Graph?



What we can see:

- **Daily Load (what you have done each day).**
- **Weekly Load 7-days (last 7-days load).**
- **Weekly Average (average weekly load from last 28-days).**

How do I *use* my Load Graph?



Pro Tips:

- DEVELOPMENT LOAD:
  - Plan your **daily training** so your **Weekly (7-days) Load line** is ***slightly above*** your **Weekly Average (28-days) Load line.**
- RECOVERY/ADAPTATION LOAD:
  - Plan your **daily training** so your **Weekly (7-days) Load line *is in line with, or slightly below*** your **Weekly Average (28-days) Load.**
- READINESS TO PERFORM LOAD:
  - Plan your **daily training** so **Weekly (7-days) Load** and **Weekly Average (28-days) Load** lines are ***close together***.

Important Considerations!

1. The App is only useful if you submit an **'Activity Status' (Matches, Training, PE, Rest) daily!** Use 'Activities' section in App to go to previous day **if you forget!**
2. Talk to your **Academy coaches and parents** *BEFORE* making any decision on training or playing load needs.
3. Don't stress if things don't go to plan… Ask your **Academy coaches** for help, as they are **always looking at this information** and understand how to best use it!

SO START USING YOUR LOAD GRAPH BY ADDING *DAILY* ACTIVITY STATUSES TO IMPROVE YOUR DEVELOPMENT, RECOVERY & READINESS TO PERFORM!

7.6 Example Feedback Channels

MyLife Digital EPD Balanced Scorecard (Work In Progress)

	Service Standard	Monthly Rolling Average		Sep-17	Aug-17	Jul-17	Jun-17	May-17	Apr-17	Mar-17	Feb-17	9/4/2017 Week 14	2/4/2017 Week 13	20 - 26 Mar 2017 Week 12	13 - 19 Mar 2017 Week 11	6 - 12 Mar 2017 Week 10	06 Mar - 11 Mar 2017
Infrastructure																	
App Availability (Uptime)	99.9%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
App Responsivness - Page Load (ms)		162.83	697.00	237.00	155.00	161.00	148.00	153.00	165.00	161.27	162.23	234.00	156.00	161.27	161		
Application Configuration																	
Total No of Clubs			8	8	8	5	5	5	4	1	1	1	1	1	1	1	1
Total No of Squads			24	21	9	9	9	9	6	2	2	2	2	2	2	2	2
Total no of Registered **Users**			563	471	136	130	127	127	92	75	14	75	74	74	74	74	14
Total number of **users** Logged In At Least Once				276	93	88	84	84	67	54	4	54					
Total No of Club Admin			35	29	10	15	14	14	11	5	5	5	5	5	5	5	5
Total No of billable Registered **Players** (billable metric)			512	428	106	106	106	106	79	66	7	66	66	66	66	66	7
Total number of **active players** Logged In At Least Once				246	71	70	70	70	56	49	4	49					
Players Not Completing Registration & Never Logged In				179	35	36	36	36	23	17	3	17					
% **Players** Not Completing Registration & Never Logged In				41.82%	33.02%	33.96%	33.96%	33.96%	29.11%	25.76%	42.86%	25.76%					
Total No of Researcher			3	3	2	2	3	4	4	3	1	3	2	2	2	2	1
Total No of Physio			13	11	5	7	5	5	3	1	1	1	1	1	1	1	1
User Involvement																	
Total no of Users who have initiated at least one session		126	962	809	100	77	80	170	125	248	5	53	43	50	81	70	131
Total no of sessions a User is actively engaged		756	6908	4061	443	396	574	910	651	1589	27	186	199	247	324	329	392
Actual - New Visitor (sessions instigated by)		109	727	775	65	58	56	130	83	240	5	20	14	18	40	30	128
% of total sessions - New Visitor (sessions instigated by)		15.43%	10.50%	19.10%	14.70%	15.70%	9.60%	14.30%	12.70%	15.10%	18.50%	10.75%	7.04%	7.29%	12.35%	9.12%	32.65%
Returning Visitor (sessions instigated by)		646	6181	3286	378	311	518	780	568	1349	22	166	185	229	284	299	264
% of total sessions - Returning Visitor (sessions instigated by)		59.73%	89.50%	80.90%	85.30%	84.30%	90.20%	85.70%	12.70%	84.90%	81.59%	89.25%	92.96%	92.71%	87.65%	90.88%	67.35%
Average length of session		00:01:58	00:00:50	00:01:03	00:08:05	00:05:42	00:05:38	00:02:35	00:01:21	00:01:53	00:02:40	00:01:01	00:01:47	00:01:42	00:01:18	00:01:58	00:02:34
Mobile Device (sessions instigated on)		702	5829	3567	240	327	556	830	589	1503	14	174	187	232	317	314	346
iOS		59.87%	90.87%	83.13%	66.67%	85.63%	93.88%	89.88%	78.44%	78.98%	22.20%	73.12%	83.42%	74.49%	80.13%	79.09%	86.42%
Andriod		22.27%	9.13%	4.65%	33.33%	14.37%	6.12%	11.20%	21.56%	15.61%	29.63%	20.43%	16.58%	19.43%	19.87%	16.06%	13.58%
Desktop Device (sessions instigated on)		54	490	494	203	42	18	80	62	86	13	12	12	17	7	26	46
Macintosh		18.91%	3.91%	7.36%	40.18%	6.78%	1.92%	5.93%	5.68%	2.89%	48.15%	3.23%	3.52%	3.64%	0.62%	3.03%	8.16%
Windows		2.11%	3.18%	4.75%	5.64%	4.61%	1.22%	2.86%	3.80%	2.52%	0.00%	3.23%	2.51%	2.43%	1.54%	1.82%	3.57%
Chrome OS			0.03%	0.05%													
Linux			0.01%														
Supportability & Service Management																	
No of Support Tickets raised			4	8	0	0	2	4	3	2	2						
No of Problems - Bugs raised			2	0	0	0	6	0	2	1	0						
No of Changes raised			1	2	0	0	0	0	1	3	2						
Planned Maintenance (hours)			00:00:15	00:00:30	00:00:00	00:00:00	00:00:00	00:00:00	00:30:00	02:30:00	02:00:00						

[redacted] Pilot Feedback

7th May 2017

[redacted] Academy Athletic Performance Manager

Q: The Product (Does the application work well? Where can improvements be made?)

We at present have been using a system called TPE. The RFU app does what it says on the tin, it is a data entry system that give interaction with the player. It is easily manageable and player friendly.

Q: Player Engagement (How have the players received the application?)

The players have not been as diligent as they could, be but like stated above we have been focussed on our staffing, and also the young boys playing in the A League Semis, Final. There is a need for an app, so with a focussed approach by staff and players the product will be successful. Issues maybe managing U16 usage, as we don't see them everyday?

Q: Player Opinion (It would be great if you could ask a sample of the players (reported to the group anonymously) to provide a small amount of feedback on the app if possible)

Will do this, this week for players that have used it and report back to the meeting

Q: Future Recommendations (What do we need to do to make this project a success)

TPE - has the ability to load videos and questionnaires - for the players to watch training clips back, and post nutritional questionnaires to assess knowledge. Is this kind of platform available?

The Club uses Kitman labs for the rest of the squad, why do we need a second system? Can Kitman not do it? - Clubs that already run monitoring systems, why do we need another?

Can we added booking systems to the platform - physio clinics or schedules for training weeks?

Q: Other useful information

The project will be good, and understand its value and worth. In the time that the project has come to light in the game, other people have already started monitoring and collecting data with other platforms and portals. We are already in the process of deciding whether or not to use TPE for next season or not, so the decisions to launch the app for September needs doing sharply, as the clubs move quicker than the union, and we will already be using a system to change it in September??

The Club uses Kitman labs for the rest of the squad, why do we need a second system? Can Kitman not do it? - Clubs that already run monitoring systems, why do we need another?

7.7 uMARS Consent and Survey

TDP Project App Survey (uMARS)

Page 1: Participant Information

Study Information

The Talented Developing Player (TDP) Project: Player Loads, Physical Qualities and relationship to Injury and Development

Researchers:

Mr. Mark Atkinson: Email: M.Atkinson@bath.ac.uk

Supervisors:

Prof. Keith Stokes: Email: K.Stokes@bath.ac.uk

Dr. Sean Williams: Email: S.Williams@bath.ac.uk

We would like you to help us evaluate a smartphone application (app) by completing a short survey. This app has been developed to collect information about the sports and life habits of talented youth rugby players in order to best support their development and safety.

Please read this information sheet carefully and ask us if you are not clear about any details of the project or what taking part would involve for you. Take your time to decide if you want to take part. It's up to you if you want to do this. If you don't then that's absolutely fine.

1 / 18

Why are we doing this research project:

Injuries are an unfortunate part of sport for youth athletes, and rugby is no different. However, there are some injuries that may be preventable through ensuring that your levels of fatigue and fitness are appropriate, and this may be especially important in young and developing athletes. It has been shown in senior professional rugby players that the physical loads associated with training and playing matches are linked to how likely it is that they get injured. Other types of 'load', like the stress of schoolwork, might also change your injury risk. These 'player loads' have been difficult to monitor in youth athletes, but smartphone applications (apps) may now allow us to collect this information more easily. Therefore, we have designed a bespoke smartphone App that will enable us to assess the relationships between your 'player loads', injury and development.

Why have you been asked to take part?

We are asking you to take part as you have been a valuable participant in the larger TDP Project and used our Elite Player Development app. Your specific feedback will be valuable in helping us understand how best to design apps and research in the future.

Do I have to take part?

No. It is up to you whether you take part in the study. You do not have to take part but the more players who take part, the more we will find out about how to design the best apps and research for players and staff. If you want to take part, you must sign a consent form say that you have read this information and you agree to be included in the study. You can withdraw from the study by contacting us at any time without giving a reason.

What would taking part involve?

You will be asked to select which academy you are/were involved in, your age group and how long you have used the Elite Player Development App for. You will then complete 25 multiple choice questions asking your opinion on the features and functions of the app. This survey is called the Users Mobile App Rating Scale (uMARS) and is used to assess the overall quality of smartphone applications by users. The survey should take between 10-15mins and will represent really valuable information for us.

2 / 18

Are there reasons why I should not take part?

If you *have not* used the Elite Player Development app there is no need for you to provide feedback.

What are the benefits of taking part?

There are no obvious direct benefits from taking part but the information you provide will help us develop better research and support for rugby players and staff in the future. You may even see some of your opinions within future studies and apps!

What are the possible disadvantages and risks of taking part?

There are no additional risks associated with taking part in this study, beyond those involved in your normal activities as part of a regional rugby academy.

Will taking part involve any discomfort or embarrassment?

No, just 10-15 minutes of your valuable time.

Who will have access to the information that I provide?

All information which is collected about you during the course of the research project will be treated as confidential and kept on a password protected file on the University of Bath's secure server. This storage of information will be done in accordance with GDPR. All information that you provide will only be able to be accessed by the researchers. All records will be treated as confidential except in the case of review by regulatory authorities (e.g. police services).

What will happen to the data collected and results of the project?

The information will be analysed by researchers at the University of Bath and used to generate reports for England Rugby, Regional Academies and as part of Academic research to further player development and welfare best practice. No personal references

3 / 18

will be made in any report.

The rules set out by the University of Bath and the Data Protection Act allow us to securely store this information for five years, after which the information will be destroyed in a secure way.

Who has reviewed the project?

This project has been given a favourable opinion by the University of Bath, Research Ethics Approval Committee for Health (REACH) [reference: EP 1617 276].

How can I stop taking part in the project after it has started?

If you agree to take part but you, or your parent/guardian later change your mind that is absolutely fine. You do not need to complete/finish the survey.

If you have completed and submitted the survey but then decide you do not want your information included in the study please let one of the researchers (details above) know within 2-weeks of completion. After 2-weeks it may not be possible to remove the information you have provided.

What happens if there is a problem?

If you have a concern about any aspect of the project you should ask to speak to the researchers who will do their best to answer any questions. If they are unable to resolve your concern, or you wish to make a complaint regarding the project, please contact the Chair of the Research Ethics Approval Committee for Health below.

Dr. James Betts

Email: j.betts@bath.ac.uk

Tel: +44 (0) 1225 38 3448

If I require further information who should I contact and how?

You can contact ***Mark Atkinson*** (details above) at the University of Bath who will be

4 / 18

happy to answer any questions that you have. Please do also talk to your ***parent/guardian*** about your decision whether to take part in this survey.

Page 2: Consent

1. If you HAVE used the Elite Player Development (EPD) App before, and are happy to provide feedback please select 'I consent' and complete the survey. NOTE: If you have NOT used the EPD App before and/or do not want to provide your feedback you are free to discontinue at this point.

- I consent

Page 3: Participant Details

3. Please select your Academy

4. Please select your Age Group

5. How long have you been using the Elite Player Development App for?

Please select exactly 1 answer(s).

- Less than a month
- 1-2 months
- 3-5 months
- 6-12 months
- More than 12 months

Page 4: Section A: Engagement

6. Entertainment: Is the app fun/entertaining to use? Does it use any strategies to increase engagement through entertainment (e.g. through games)?

- (1) Dull, not fun or entertaining at all
- (2) Mostly boring
- (3) OK, fun enough to entertain user for a brief time (<5 minutes)
- (4) Moderately fun and entertaining, would entertain user for some time (5-10 minutes)
- (5) Highly entertaining and fun, would stimulate repeat use

7. Interest: Is the app interesting to use? Does it present its information in an interesting way compared to other similar apps?

- (1) Not interesting at all
- (2) Mostly uninteresting
- (3) OK, neither interesting nor uninteresting; would engage user for a brief time (< 5 minutes)
- (4) Moderately interesting; would engage user for some time (5-10 minutes)
- (5) Very interesting, would engage user in repeat use

8. Customisation: Does the app allow you to customise the settings and preferences that you would like to (e.g. sound, content and notifications)?

- (1) Does not allow any customisation or requires setting to be input every time
- (2) Allows insufficient customisation limiting functions
- (3) Basic customisation to function adequately
- (4) Allows numerous options for customisation
- (5) Allows complete tailoring to the individuals characteristics/preferences,

remembers all settings

9. Interactivity: Does the app allow user input, provide feedback, contain prompts (reminders, sharing, options, notifications etc)?

- (1) No interactive features and/or no response to user interaction
- (2) Some, but not enough interactive features which limits app's functions
- (3) Basic interactive features that function adequately
- (4) Offers a variety of interactive features/feedback/user input options
- (5) Very high level of responsiveness through interactive features/feedback/user input options

10. Target Group: Is the app content (visual information, language, design) appropriate.

- (1) Completely inappropriate/unclear/confusing
- (2) Mostly inappropriate/unclear/confusing
- (3) Acceptable but not specifically designed for the target audience. May be inappropriate/unclear/confusing
- (4) Designed for the target audience, with minor issues
- (5) Designed specifically for the target audience, no issues found

Page 5: Section B: Functionality

11. Performance: How accurately/fast do the app features (functions) and components (buttons/menu) work?

- (1) App is broken; no/insufficient/inaccurate response (e.g. crashes/errors etc)
- (2) Some functions work, but lagging or contains major technical problems
- (3) App works overall. Some technical problems need fixing/slow at all times
- (4) Mostly functional with minor problems
- (5) Perfect/timely response; no technical errors/contains a loading time left indicator

12. Ease of use: How easy is it to learn how to use this app; how clear are the menu options/icons and instructions?

- (1) No/limited instructions; menu options/icons are confusing; complicated
- (2) Takes a lot of time or effort
- (3) Takes some time or effort
- (4) Easy to learn how to use the app (or has clear instructions)
- (5) Able to use app immediately; intuitive; simple

13. Navigation: Does moving between screens make sense; Does the app have all necessary links between screens?

- (1) No logical connection between screens at all/navigation is difficult
- (2) Understandable after a lot of time/effort
- (3) Understandable after some time/effort
- (4) Easy to understand/navigate
- (5) Perfectly logical, easy, clear and intuitive screen flow throughout, and/or has shortcuts

Page 6: Section C: Aesthetics

14. Layout: Is arranged and size of buttons/icons/menus/content on the screen appropriate?

- (1) Very bad design, cluttered, some options impossible to select/locate/see/read
- (2) Bad design, random, unclear, some options difficult to select/locate/see/read
- (3) Satisfactory, few problems with selecting/locating/seeing/reading items or with minor screen size problems
- (4) Mostly clear, able to select/locate/see/read items
- (5) Professional, simple, clear, ordered, logical, organised; every design component has a purpose

15. Graphics: How high is the quality /resolution of graphics used for the buttons/icons/menus/content?

- (1) Graphics appear amateur, very poor visual design - disproportionate, completely stylistically inconsistent
- (2) Low quality/low resolution graphics; low quality visual design - disproportionate, stylistically inconsistent
- (3) Moderate quality graphics and visual design (generally consistent style)
- (4) High quality/resolution graphics and visual design - mostly proportionate, stylistically consistent
- (5) Very high quality/resolution graphics and visual design - proportionate, stylistically consistent throughout

16. Visual Appeal: How good does the app look?

- (1) Ugly, unpleasant to look at, poorly designed, clashing mismatched colours
- (2) Bad - poorly designed, bad use of colour, visually boring

- (3) OK - average, neither pleasant, nor unpleasant
- (4) Pleasant - seamless graphics - consistent and professionally designed
- (5) Beautiful - very attractive, memorable, stands out; use of colour enhances app features/menus

Page 7: Section D: Subjective Quality

17. Would you recommend this app to people who might benefit from it?

- I would not recommend this app to anyone
- There are very few people I would recommend this app to
- There are several people whom I would recommend this app to
- There are many people I would recommend this app to
- I would definitely recommend this to everyone

18. How many times do you think you would use this app in the next 12-months if it was relevant to you?

- None
- 1-2
- 3-10
- 10-50
- >50

19. Would you pay for this app?

- No
- Maybe
- Yes

20. What is your overall rating of this app?

- (1 out of 5) One of the worst apps I've used
- (2 out of 5)
- (3 out of 5) Average
- (4 out of 5)
- (5 out of 5) One of the best apps I've ever used

Page 8: Section E: Education

21. Awareness: This app is likely to increase my awareness of the importance of my athlete workload management, wellbeing and injury prevention?

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

22. Knowledge: This app is likely to increase my knowledge/understanding of my athlete workload management, wellbeing and injury prevention?

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

23. Attitudes: This app is likely to change my attitudes toward improving my athlete workload management, wellbeing and injury prevention?

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

24. Intention to change: This app is likely to increase my intentions/motivation to address my athlete workload management, wellbeing and injury prevention?

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

25. Help Seeking: This app would encourage me to seek further help to address my athlete workload management, wellbeing and injury prevention?

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

26. Behaviour Change: Use of this app is likely to help me improve my athlete workload management, wellbeing and injury prevention behaviours?

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

Page 9: Final page

Thank you for completing the TDP Project App Survey.

Good luck with your rugby!

Key for selection options

3 - Please select your Academy
- Bath Rugby
- Bristol Bears
- Exeter Chiefs
- Gloucester Rugby
- Harlequins
- Leicester Tigers
- London Irish
- Newcastle Falcons
- Northampton Saints
- Sale Sharks
- Saracens
- Wasps
- Worcester Warriors
- Yorkshire Carnegie

4 - Please select your Age Group
- Under-15
- Under-16
- Under-18