UNIVERSITY OF WINCHESTER

Athlete Monitoring in Elite Sport

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Doctor of Philosophy

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For Cora.

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> *Door:* Why, it's simply impassible!
>
> *Alice:* Why, don't you mean impossible?
>
> *Door:* No, I do mean impassible <chuckles>. Nothing's impossible!
>
> *Lewis Carroll*

UNIVERSITY OF WINCHESTER

Abstract

Athlete Monitoring in Elite Sport

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Doctor of Philosophy July 2020

Purpose: Athlete monitoring systems (AMS) are employed widely in elite sport. Despite this, difficulties in executing research within elite sporting organisations means that the typical AMS practices and the value end-users place in their AMS remains under-reported. A range of methodological and implementation issues for AMS have been previously described e.g. poor stakeholder buy-in. This is concerning, because if an AMS fails to be effective, poor athletic performance or maladaptation may occur. Therefore, elucidating current monitoring practices within elite sport and providing guidance to address any implementation issues encountered has the potential to provide a significant contribution to research within this area. ***Aim:*** To explore athlete monitoring practices in elite sport and the utility of a behavioural change intervention to improve buy-in to monitoring. ***Methods:*** A survey was used to gather the opinions of elite sport practitioners on their AMS, and semi-structured interviews captured athlete and coach AMS perceptions. A behaviour change intervention, which aimed to improve the engagement of elite athletes with their AMS, was assessed for its utility. ***Results:*** For the first time, this study was able to reveal the extent of AMS customisation across a range of elite sports. Consequences of this approach included: significant subjective-questionnaire variability, reduced scientific methodological rigour, limited -practitioner confidence in their data and difficulty discerning meaningful change within it. AMS adherence was not found to be enhanced by a formalised behavioural change intervention. ***Conclusion:*** Customisation of athlete monitoring metrics has reduced the scientific rigour of AMS. Further, the fast changing landscape in elite sport makes it challenging to apply a behaviour change intervention to modify AMS adherence. In an effort to resolve these AMS implementation issues, a series of recommendations for the applied practitioner working with AMS were compiled, thus providing an original contribution to knowledge in both applied practice and research.

Keywords: *Elite, Athlete, Monitoring, Buy-in, Behaviour Change, Engagement, High-Performance, Coach, Training.*

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Presentations:

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Neupert, E. C., Gupta, L., Holder, T. & Jobson, S. A. (2019, March). *PhD Overview: Athlete Monitoring at the English Institute of Sport* [Conference presentation]. Athlete Health Team Conference, English Institute of Sport, Loughborough, United Kingdom.

Neupert, E. C., Gupta, L., Holder, T. & Jobson, S. A. (2019, March). *Athlete Wellbeing Monitoring: Insights from the Frontline* [Conference presentation]. Physiology Team Conference, English Institute of Sport, Bisham Abbey, United Kingdom.

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Neupert, E. C., Cotterill, S. T., & Jobson, S. A. (2016, November). *Best Practices and Strategies to Implement Training Monitoring in Elite Sport* [Conference presentation]. Sport Innovation Conference, Calgary, Canada

Working Group:

Part of the athlete monitoring review group at the English Institute of Sport

List of Contents

List of Tables

List of Figures

Acronyms

AMS:	Athlete Monitoring System
APEASE:	Acceptability, Practicability, (Cost) Effectiveness, Affordability, Safety/Side-Effects, Equity
COM-B:	Capability, Opportunity, Motivation and Behaviour Model
DALDA:	Daily Analysis of Life Demands for Athletes
MDT:	Multi-Disciplinary Team (sports science and medicine practitioners)
POMS:	Profile of Mood States
RED-S:	Relative Energy Deficiency in Sport
REST-Q:	Recovery Stress Questionnaire for Athletes
RPE:	Rating of Perceived Exertion
SDRS:	Social Desirability Response Scale
sRPE:	Session Rating of Perceived Exertion (training duration x RPE)
SSM:	Sport Science Managers
TRIMP:	Training Impulse
TTM:	Transtheoretical model for behaviour change

Operational Definitions

Adherence: The rate of completion of athlete monitoring in relation to expectation from the sporting organisation, typically in this thesis presented as a percentage.

Athlete Monitoring: The capture of data related to athletic training and performance e.g. athlete self-report measures.

Athlete Monitoring Metrics/Measures: The subjective and/or objective parameters collected during athlete monitoring e.g. heart rate.

Athlete Monitoring System: The platform on which athlete monitoring data is captured e.g. MS Excel or mobile application software.

Behaviour Change: A modification or change in the way an individual or group acts or conducts themselves (Michie et al., 2014)

Behaviour Change Intervention: Systematically applying theory and evidence to design and evaluate a coordinated set of activities to change specified behaviour patterns (Michie et al., 2014).

Big-data: An extremely large, complex and heterogeneous data set incorporating different data types. Typically the data accumulates rapidly and requires advanced computational methods to reveal patterns and trends.

Buy-in: An individual's cognitive, (attitude and beliefs) and behavioural, (actions) commitment to the process of athlete monitoring (Mathews & Crocker, 2014).

Coach: An individual appointed to support, train and guide athletes towards improved athletic performance.

Complex System: A system which comprises of a variety of actors. The behaviour of each actor adapts and responds to the behaviours of others within the system (Gomersall, 2018). For example an elite sport and its various sporting organisations and bodies.

Custom measures: This refers to athlete monitoring measures which those within the sporting organisation have typically created themselves. Such custom measures are stereotypically not subject to the same rigorous process of checking validity and reliability as seen for published measures.

Ecological/Holistic Approach or Lens: Rather than just considering "the athlete" in isolation, an ecological approach or lens takes a broader look at the athlete and their sporting

environment. A holistic ecological approach extends that concept further to include the athlete's environment beyond their sporting domain e.g. education, home-life etc.

Elite: Those affiliated with a national team (senior or junior) from a National Governing Body of Sport and competing at the highest level within their sport. This is classed as both competing and achieving success at national and international level.

End-users: Those that use the athlete monitoring system in day-to-day practice. Typically, this refers to the athlete and coach, but can also include practitioners.

Engagement: Often used interchangeably used with the term 'buy-in," operationally however engagement with athlete monitoring is the product of buy-in and typically indicates a move towards a more informed and reasoned involvement with athlete monitoring.

Hostile surveillance/environment: Hallmarks of an environment where an AMS can negatively impact those being surveilled may include: the AMS invoking feelings of fear, anxiety and precariousness, privacy concerns, a lack of personal and professional boundaries, opaque data analysis, decision-making that is not easily challenged, and athletes trying to subvert monitoring.

Load (Internal and External): External load is the work completed by the athlete, independent of their internal characteristics, e.g. power output. Internal load is the relative physiological and psychological stress that training places on the athlete e.g. RPE

Meaning Units: This refers to the frequency of comments within an interview transcript that were categorised to a specific theme e.g. feedback.

Multidisciplinary Team: A group of individuals from varying sports science and medicine backgrounds that work to support the coach and athlete dyad achieve improved athletic performance.

National Governing Body: An organisation that administers a sport on a national basis for the United Kingdom.

Practitioner: An individual appointed to provide sports science or sports medicine support to athletes. Examples include physiologists and psychologists.

Sport or Sporting Organisation: A given Olympic or Paralympic discipline, typically represented by a National Governing Body of Sport e.g. British Rowing. Colloquially, 'The Sport' is used to delineate not only the discipline, but those individuals, particularly management, who work within the sport.

Stakeholders: People with an interest in athlete monitoring, typically this includes the coaching team, athletes, sports science and medicine practitioners, managers and funders (UK Sport and the English Institute of Sport).

Training status: The balance between an athlete's fitness and fatigue levels (Banister et al., 1975).

Validated measures: Athlete monitoring metrics which have been through a rigorous process of analysing the validity and reliability of the measure. Typically, this means the measure has also been published in peer-reviewed scientific journals e.g. REST-Q athlete self-report measures.

Validity: An umbrella term encompassing face, criterion, construct and content validity. For AMS, construct validity is arguably the most rigorous form of validity that should be established (Gratton & Jones, 2010; Saw et al., 2017)

1.0 Chapter One - Introduction

1.1 Background

Milo of Croton, a renowned ancient Greek Olympic wrestler (Foster et al., 2017), is thought to be one of the first examples of athletes undertaking a recorded training programme. Milo was said to have carried a newborn calf on his shoulders everyday as part of his wrestling training until finally the calf became a four-year-old bull, which he was still able to lift. This training programme, which today would be akin to progressive overload resistance training (Bompa, 1999), was adopted by other athletes of the time due to Milo's established athletic prowess (Grivetti & Applegate, 1997). More contemporary monitored programmes can be traced back to Germany in the 1930s, where interval training was developed by Coach Woldemar Gerschler (Foster et al., 2017). Gerschler utilised heart rate recovery rates between interval repetitions to dictate training volumes and loads. This concept was developed further through coaches developing index workouts that were linked to performance on the track, such as the 10 x 400m prescribed and popularised by Frank Stampfl, Sir. Roger Bannister's coach (Foster et al., 2017).

Athlete monitoring, the focus of this thesis, has been described as the process of collecting, analysing and providing feedback on measures relating to training and performance. This typically includes both internal and external training load parameters (Coutts & Cormack, 2014). The end goal of the collection of athlete monitoring data is to support the coach in optimising athletic performance and minimising undesirable outcomes such as injury or illness (Bourdon et al., 2017).

The majority of athlete monitoring during the early to mid-1900s sought to quantify and explore external loading factors imposed by training programmes. External load has been defined as the work completed by the athlete, independent of their internal characteristics, e.g. power output sustained during a time trial (Wallace et al., 2009). Only more recently has there been a focus on examining the impact of these external loading patterns on the athlete themselves. This concept has been termed internal load, i.e. the relative physiological and psychological stress that training places on the athlete (Halson, 2014). As the measurement of external load can vary widely depending upon the sport type (Coyne et al., 2018), measures of internal load, e.g. rating of perceived exertion (RPE), are commonly applied to assess internal load across a broad range of sports (Taylor et al., 2012). Therefore, in this thesis the measurement of internal load parameters, often termed athlete self-report measures (Saw et al., 2015c), provides a specific anchor point with which to make cross-sport comparisons.

The process of athlete monitoring has gained significant momentum in elite sport, with research indicating widespread use of a series of internal and external load measures in elite Australasian sport (Taylor et al., 2012) and premiership football (Akenhead & Nassis, 2016; Weston, 2018), alongside an increase in published research in athlete monitoring (see Figure 1). Nonetheless, no data describing cross sport athlete monitoring practices has been published for the elite sport system in the United Kingdom. This lack of information could be the result of the culture of secrecy surrounding elite sport data (De Bosscher et al., 2008). Unfortunately, this secrecy makes it unclear whether athlete monitoring systems (AMS) used in elite sport follow evidence-based practice, or if they provide value to elite sport practitioners.

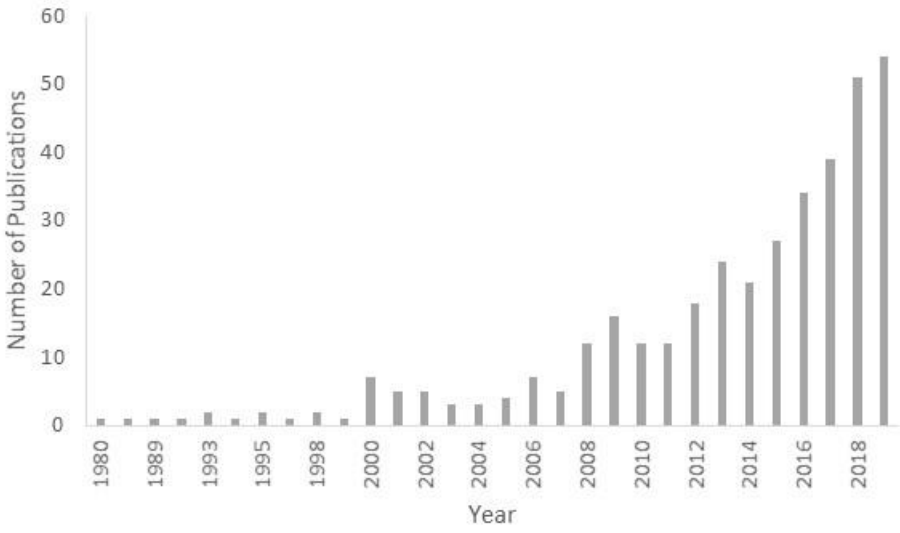

Figure 1. Using the Scopus database the number of publications per year with the search terms, "Athlete monitoring AND elite sport," were returned from the Scopus database (Elsevier, n.d.).

While the current athlete monitoring landscape across elite sport in the United Kingdom is unclear, the use of AMS as a tool to support performance optimisation and reduce illness/injury incidence has been much discussed (Halson, 2014; Lambert & Borresen, 2009). Research has made some advances in establishing best practice for the implementation of AMS (Saw et al., 2017), suitable monitoring markers (Bourdon et al., 2017; Saw et al., 2015c), and data analysis methods (H. R. Thornton et al., 2019). Nonetheless, significant issues with AMS have been highlighted, these include: uncertain measure validity (Carey et al., 2018; Taylor et al., 2012), poor athlete adherence (Barboza et al., 2017), and use of inappropriate data analysis techniques (Coyne et al., 2018; Saw et al., 2017). Thus, while many practitioners in elite sport use an AMS (Taylor et al., 2012), there is evidence that best practice research in

athlete monitoring is not being applied in elite sport practice; however, the extent to which this is a problem is unclear due to a lack of published data.

Given the recent spotlight on athlete health in elite sport (Roan, 2018), robust athlete monitoring is one method to safeguard the health of athletes. Due to the importance placed on athletic performance and health, it is therefore critical that AMS function effectively (Bourdon et al., 2017). Elite athletes are particularly vulnerable to under-recovery given the high training loads, limited recovery periods and the high-stakes environment in which they perform (Collins & Cruickshank, 2012; Halson, 2014). Preventing athlete maladaptation and using athlete monitoring as a tool to promote performance gains is particularly important in the elite sport environment, as high training loads and limited recovery periods can increase an athlete's chance of maladaptation (Halson, 2014). Recorded incidences of overtraining or maladaptation are reportedly higher in elite athletes than the general population (Lewis, Collins, et al., 2015; Meeusen et al., 2013). Therefore, an AMS that identifies athlete maladaptation can inform decisions to modify athlete training programmes to mitigate the impact of any maladaptation. An AMS that is unable to identify athlete maladaptation could lead to incidences of insufficient recovery being overlooked and athletes subsequently becoming unwell. Understanding whether AMS are perceived to function effectively, as explored in this thesis, is therefore an important research area to explore.

A well-functioning AMS can reveal an athlete's response to both historical and current training stimuli, and guide subsequent programmatic decisions. This is important, because on an international competitive sporting stage the differences between first and last place can be very small, thus the headroom to improve athletic performance is marginal (Hopkins, 2004; Turner & Comfort, 2017). Accordingly, elite athletes are more likely to benefit from the targeted and individualised training insights an AMS provides in comparison to their sub-elite peers, who have greater headroom to improve their performance (Seiler, 2010).

AMS therefore serve a dual role: the prevention of athlete maladaptation; and the optimisation of performance. Ensuring an AMS is fit for purpose in the elite sport environment is therefore critical, especially given the relative scarcity of elite amateur athletes. To this end, UK Sport has reported that ~1300 athletes are part of their funded programmes at either 'Podium' (medallists at major international championships) or 'Podium Potential' level (top 8 placing at major international championships) (*World Class Programme | UK Sport*, n.d.). These figures represent approximately 0.002% of the population of the United Kingdom, or 0.007% of the population between the ages of 18-39, i.e. the age range of those who are most likely to complete within elite level sport (Allen & Hopkins, 2015; *Population estimates - Office for National Statistics*, n.d.). These statistics demonstrate the relative rarity of elite athletes within

the population. It also underlines the importance of ensuring any AMS is fit for purpose, supports performance optimisation and prevents athlete maladaptation in such a unique cohort of individuals.

Currently, there are limited published insights into athlete monitoring practices in elite sport. Therefore, the concerns raised regarding the scarcity of elite athletes, their susceptibility to illness/injury and the need to individualise their training to ensure continued performance improvements, gives a strong rationale to further investigate the role AMS play within elite sport in the United Kingdom. Researchers have also previously discussed difficulties in accessing the elite sport population for research purposes (Coutts, 2016). Any research pertaining to elite athletes and AMS practices is therefore likely to provide a significant and original contribution to research in this area. This originality of research area further complements the rationale to explore the use of AMS in elite sport in this thesis. Therefore, the role of AMS in elite sport are explored in Chapters 4 and 5 of this thesis.

Following from the data collected in Chapters 4 and 5, the buy-in and engagement of athletes with their AMS was identified as a significant barrier to being able to successfully implement an AMS. Prior to the work in this thesis, poor athlete adherence had been noted by researchers (Barboza et al., 2017; Saw et al., 2015b) but the reasons for it were unclear. Chapter 6 therefore sought to articulate the reasons for poor athlete adherence to AMS in a cohort of elite athletes. This is important, because understanding why athletes choose not to complete their monitoring i.e. engaging in an undesirable behaviour, has been proposed as a critical step towards trying to modify that behaviour (Michie et al., 2014). This concept of first understanding the reasons behind undesirable behaviour has been advocated by researchers (Donaldson & Finch, 2012; Prestwich et al., 2013).

In order to address some of the issues around engagement of stakeholders with the AMS (Chapters 4, 5 and 6), Chapter 7 therefore examined the practicalities of implementing a behaviour change intervention to address poor athlete adherence. If a behaviour change intervention is able to be successfully implemented, this may positively influence AMS adherence, which can in turn aid sporting organisations in their work to optimise performance and reduce maladaptation via their AMS (Bourdon et al., 2017). While systematic behaviour change interventions are frequently used in health research, for example to reduce sedentary behaviour (Munir et al., 2018), to date there has been little published use of them within elite sports beyond a nutritional intervention (Costello et al., 2018). There is however evidence that elite sport use informal behaviour change techniques to modify athlete AMS adherence, such as athlete education (Saw et al., 2017) and promoting visible usage of AMS in practice (Duignan et al., 2019b). Systemised and evidence-based behaviour change interventions have

however been demonstrated to be more effective at bringing about desired behaviour change in comparison to their non-evidence-based counterparts (Davis et al., 2015). Therefore, Chapter 7 investigated the practicalities of using a formal behaviour change intervention within elite sport to improve athletes' adherence to their AMS.

1.2 Specific Focus: Research Questions, Aims and Hypotheses

This thesis aims to explore athlete monitoring practices and perceptions in elite sport in the United Kingdom and whether a behaviour change intervention to improve athlete adherence can be implemented in an elite sport setting. In particular, the individual chapters investigate the following research questions outlined below. Hypotheses are presented for Chapters 5 and 7 where the hypotheses were able to be tested, but not in Chapters 4, 6 and 10. This is a result of the experimental design of Chapters 4 and 6, which used inductive and exploratory methods. Or, in the case of Chapter 10, where findings from this thesis were summarised into practical applications and a hypothesis was therefore deemed unnecessary. However, it is recognised that the production and testing of hypotheses in qualitative research is contested (Celo et al., 2008; Chigbu, 2019).

a. **Chapter 4:** What are the current athlete monitoring practices in elite sport in the United Kingdom?

   Aim: To determine what parameters are being monitored in elite sport in the United Kingdom, and how these parameters are collected, analysed and fed back to key stakeholders within the sporting organisation.

b. **Chapter 5:** Do practitioners value their athlete monitoring systems in elite sport in the United Kingdom?

   Aim: To ascertain if practitioners in elite sport in the United Kingdom perceive their athlete monitoring system to be effective. To identify issues that practitioners perceive may negatively impact the efficacy or value of their athlete monitoring system.

   Alternative Hypotheses:
   Practitioner confidence will be higher in their athlete self-report measures where:
   (H_1) Practitioners report that there is a scientific underpinning to their AMS.
   (H_2) Practitioners report that meaningful changes in their AMS data are acted upon.

   Higher athlete adherence rates to an AMS will be present where:
   (H_3) Practitioners report that coaches provide support to their AMS.
   (H_4) Practitioners report that athletes receive sufficient AMS feedback.

   Where meaningful change in AMS data is reportedly acted upon:
   (H_5) Practitioners will report increased coach support for their AMS.
   (H_6) Practitioners will report that there is scientific evidence underpinning their AMS.

c. **Chapter 6:** What are the reasons for poor athlete adherence to athlete monitoring systems?

Aim: To explore a cohort of athletes' perceptions of their athlete monitoring system in order to identify common themes, and problems, that may inhibit adherence to monitoring.

d. (i) **Chapter 7:** Can a behaviour change intervention to increase athlete adherence to monitoring be successfully implemented in an elite sporting organisation?

Aim: To determine the practicality of using a formalised and evidence-based behaviour change intervention to improve athlete adherence to monitoring within an elite sporting organisation.

Alternative Hypothesis:
H_1: That the majority of the behaviour change targets (≥75%), identified using the behaviour change intervention will be fully implemented.

(ii) **Chapter 7:** Can a behaviour change intervention increase athlete adherence to an athlete monitoring system in an elite sporting organisation? *(Contingent on di rejecting the null hypothesis)*

Aim: To determine if a behaviour change intervention can increase adherence over a 6-month period.

Alternative Hypothesis:
H_2: The behaviour change intervention will increase athlete monitoring adherence rates.

e. **Chapter 10:** What are the practical applications based upon the findings of this thesis for practitioners working in elite sport?

Aim: To produce a series of recommendations and guidelines for elite sport practitioners which extend existing work (Saw et al., 2017). *To provide practitioners with a resource which can help them improve athlete monitoring practice based upon the findings from this thesis.*

1.2.1 Reflective Note: Arriving at the Specific Focus

The original research direction of this thesis was set to pursue performance questions examining the reliability and predictive qualities of athlete monitoring data in partnership with the English Institute of Sport and a National Governing Body of sport. Therefore, at the outset of this research the National Governing Body of Sport, in conjunction with the author of this thesis, launched daily athlete monitoring with their senior national team. Despite receiving support from the majority of stakeholders within the team (e.g. athletes, coaches, sports science practitioners and management), it quickly became apparent that there were significant issues surrounding the viability of the AMS, particularly in relation to athlete adherence.

Consequently, the original research focus was suspended due to the inability to collect sufficient data to enable meaningful data analysis. While it is tempting to gloss over this recalibration of direction, it is highly relevant, as it reflects problems that are often

experienced when implementing research at the coalface of elite sport and further underpins the rationale for the specific focus of this thesis (Coutts, 2016). Instead, a new research question examining the efficacy of AMS in elite sports was proposed to address why, despite all efforts with the National Governing Body, the AMS had not achieved sufficient athlete engagement. Anecdotally it was also becoming apparent that issues surrounding AMS efficacy were not isolated to this particular National Governing Body. Discussions with colleagues working in other elite sporting organisations indicated that poor athlete adherence was commonplace; athlete monitoring measures frequently lacked scientific rigour and, due to both privacy and intellectual property concerns, personnel within different sports were not able to learn from each other's mistakes, nor was best practice easily shared.

Where athlete monitoring efficacy is deemed to be poor, the implications could be significant as it could result in unexplained or poor performance, and uncertain illness/injury risk. This is where the research questions in this thesis were borne from: a real-world problem that appeared to permeate many sporting organisations within the United Kingdom.

1.3 Thesis Outline

1.3.1 Literature Review Overview

Chapter 2 encompasses topics directly related to athlete monitoring, and its pertinence to the elite sport (Olympic and Paralympic) environment. It covers the importance of athlete monitoring in elite sport, the monitoring tools that are commonly used, and current trends and issues relating to these measurements. The potential implications of failing to act on the signs of maladaptation are explored, along with how barriers to implementing AMS, such as athlete engagement may negatively impact AMS efficacy. Overall the literature review aims to take the reader on a journey to help them understand why athlete monitoring is important in elite sport, what we do and don't know about the use of athlete monitoring in elite sport, and factors that appear to impact the efficacy of monitoring in elite sport.

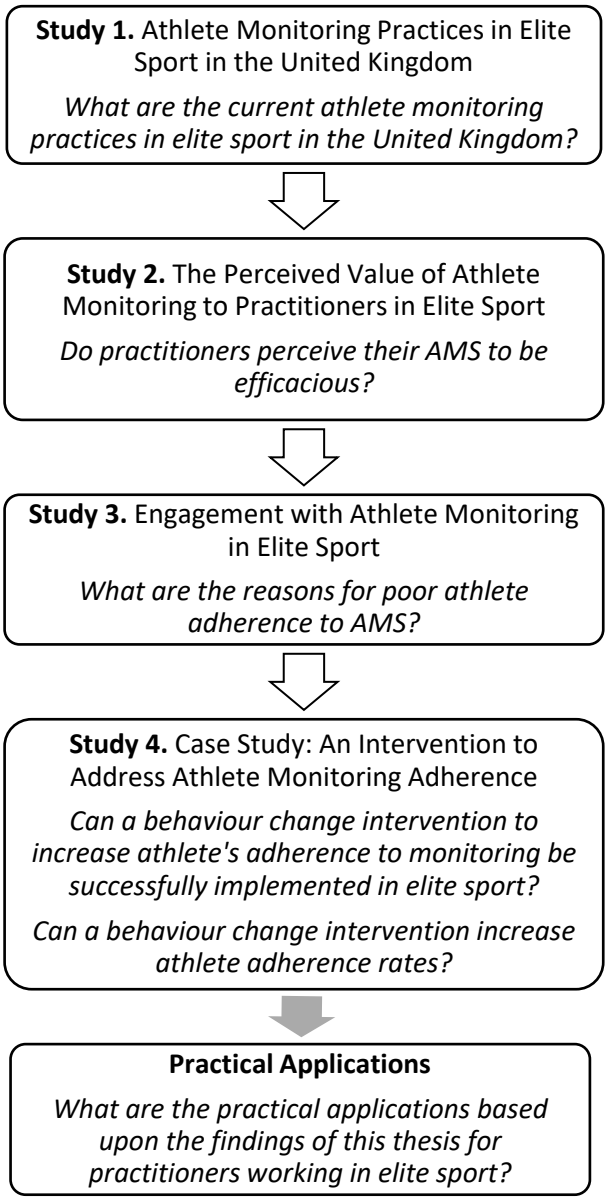

Figure 2. Thesis outline with study titles and research questions.

1.3.2 Study 1: Athlete Monitoring Practices in Elite Sport in the United Kingdom

The aim of study 1 was to determine what parameters are being monitored in elite sport in the United Kingdom, and how these parameters are collected, analysed and fed-back to key stakeholders within the sporting organisation. The paucity of information pertaining to current athlete monitoring practices in elite sport, combined with concerns relating to scientific rigour (Taylor et al., 2012), established a clear need for this study. Study 1 examined current athlete monitoring practices across a broad range of Olympic and Paralympic sports in the United Kingdom, with data collected from elite sport practitioners via a secure online questionnaire. Details pertaining to how practitioners working in elite sports gathered their athlete monitoring data, what they measured, how they measured it, and subsequently how the data was analysed and disseminated to key stakeholders were explored. Any disparities between

what is considered best practice from published research and applied athlete monitoring practice were identified and discussed, with some potential solutions proposed.

1.3.3 Study 2: The Perceived Value of Athlete Monitoring to Practitioners in Elite Sport

The aim of study 2 was to ascertain whether practitioners in elite sport in the United Kingdom perceived their athlete monitoring system to be effective. It was also to identify issues that practitioners perceive may negatively impact the efficacy or value of their athlete monitoring system. This study is important, as, to date, there has been a focus on 'how and what' to monitor athletes, but less emphasis on the perceived efficacy of an AMS. Therefore, while claims regarding the ability of AMS to support performance optimisation and injury/illness prevention have been made (Gabbet et al., 2017; Halson, 2014; Hulin et al., 2014), there is little insight into whether AMS provide value to practitioners in elite sport, beyond what has been reported in Premiership Football (Akenhead & Nassis, 2016; Weston, 2018). Accordingly, the perceptions of AMS efficacy in seventy-five practitioners working in elite sport in the United Kingdom were sought.

1.3.4 Study 3: Engagement with Athlete Monitoring Systems in Elite Sport

This study explored a cohort of athletes' perceptions of their athlete monitoring system in order to identify common themes and barriers that may inhibit adherence to monitoring. This is important, because AMS have been shown to be challenging to effectively implement and sustain athlete engagement with in elite sport (Barboza et al., 2017; Saw et al., 2015b). The issue of poor athlete engagement was highlighted by the results of study 2. This study examined issues and barriers to engagement with and implementation of the AMS, as reported by the athletes during semi-structured interviews. A novel approach advocating the use of a behaviour change model (Michie et al., 2011) was proposed, which aimed to change behaviours to improve AMS adherence.

1.3.5 Study 4: An Intervention to Address Athlete Monitoring Adherence

This study aimed to determine the practicality of using a formalised and evidence-based behaviour change intervention - the behaviour change wheel (Michie et al., 2014) - to modify adherence to athlete monitoring within elite sport. Athletes and coaches within a combat sport were interviewed on their perceptions of their AMS pre and post a behaviour change intervention targeted at increasing athlete engagement with their AMS. Both the feasibility of using the behaviour change wheel to modify athlete adherence in an elite sport setting was addressed, in combination with an analysis of the change in athlete AMS adherence rates. As poor adherence to AMS has been shown to be a significant barrier to successful AMS

implementation, if a behaviour change intervention is able to address this issue, the completeness, and thus utility of the AMS data should be improved.

1.3.6 Discussion, Conclusion and Practical Applications

In order to contextualise the findings from this thesis, the results are discussed in relation to implications for applied practice. This is summarised by responding to three questions: 1) Does the gap identified between applied practice and applied practice matter? 2) What is the impact of athlete monitoring data in elite sport? 3) How can we improve athlete monitoring in elite sport? A synopsis of the main findings and practical implications is then provided in the Chapter 8.

In Chapter 10, the findings from this thesis are summarised in recommendations and guidance for applied practice in the form of frequently asked questions. Existing guidance (Saw et al., 2017) has also been expanded (see Figure 13) to include practical recommendations that were identified to be otherwise missing from the literature. This was felt to provide a novel contribution to the literature in combination with the novel use of the behaviour change wheel in an elite sport setting (Michie et al., 2014).

2.0 Chapter Two - Literature Review

2.1 Conceptual Models of Training

Understanding an athlete's balance of fitness, fatigue and recovery is fundamental to support their training programme and performance optimisation. Training programme monitoring enables patterns in the relationship between fitness, fatigue and performance to be discerned (Borresen & Lambert, 2009). Through monitoring individual adaptation to training, coaches and sports scientists can make informed and evidence-based modifications to training programmes. This can reduce the risk of negative outcomes such as illness and non-functional overreaching, and increase the likelihood of performance gains (Abbott et al., 2018; Wrigley et al., 2012).

A well planned and implemented training programme can stimulate positive training adaptations by exposing an athlete to a stress of sufficient intensity, frequency, volume and/or duration to elicit an improvement in athletic performance (Smith, 2003). Coaches may choose to target one or more domains within a training programme, such as physical, psychological or technical areas, to bring about positive performance gains (Åstrand et al., 2003; Bompa, 1999).

An athlete's response to training within the physical domain has been described by the relationship between work, i.e. a training stimulus, and recovery. In order to explain how an athlete may respond to a physical training stimulus, a generic theoretical model has been proposed showing the relationship between training and fatigue. Figure 3 shows this model and the phenomenon known as the supercompensation cycle. Here, a training stimulus results in transient decrements to performance. Following a period of recovery, improved athletic performance is then demonstrated. This is eventually followed by a return to homeostasis and baseline fitness and performance levels if no subsequent training stimulus is applied (Bompa, 1999; Selye, 1950; Yakovlev, 1955).

A well-planned and periodised training programme balances the training stimulus and fatigue seen in phase I (Figure *3*), allowing the coach and athlete the opportunity to take advantage of the supercompensation phenomenon seen in phase III. This aids improvement in an athlete's fitness levels over time, thus enhancing performance (Mujika, 2009). However, if the planned recovery is insufficient or the frequency, intensity or volume of training stimuli is more than the athlete can tolerate, no return to homeostasis is seen in phase II and a subsequent decrement in performance may be observed (Bompa, 1999).

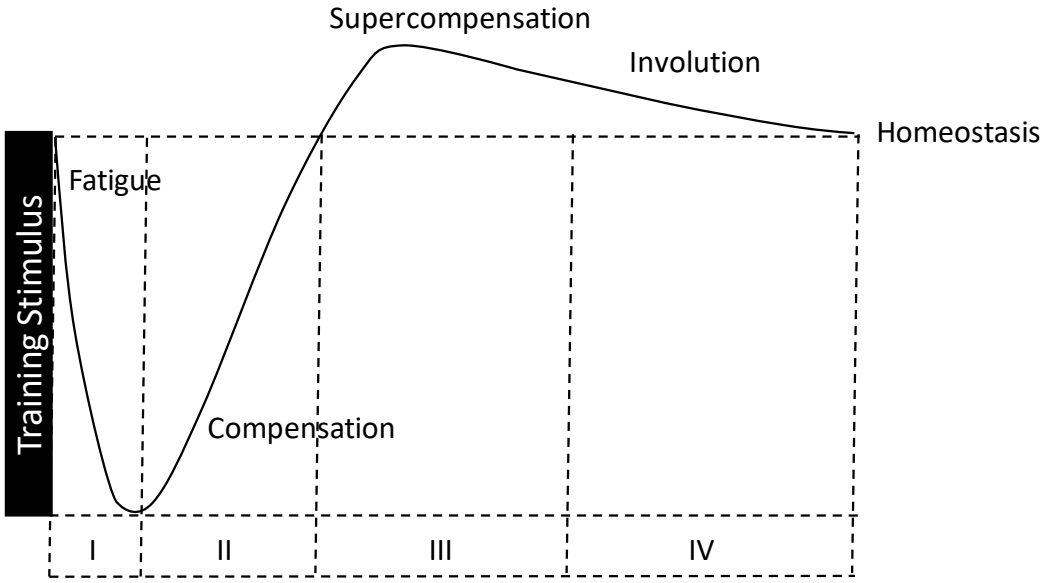

Figure 3. Supercompensation cycle following a training impulse with the line representing changes in fitness level (adapted from Bompa, 1999).

The supercompensation model, first conceived as the General Adaptation Syndrome, describes how the body reacts and adapts to stress before returning to homeostasis (Selye, 1950). Homeostasis is the ability of the body to maintain balance or equilibrium across a range of biological processes, and in the face of perturbations to that balance (McArdle et al., 2015). The General Adaptation Syndrome is widely accepted in sports science, spawning multiple theories of training programming and periodization (Bompa, 1999).

More contemporary theories such as allostasis, where “a set of collaborative processes deploy resources to preserve functionality of the human body” (Kiely, 2018), have recently challenged the underpinning assumptions of the General Adaptation Syndrome, particularly in relation to individualisation of responses, and the impact of non-physical factors on the stress response (Kiely, 2018). However, the concept of allostasis has yet to be incorporated into training theory zeitgeist (Sterling & Eyer, 1988). As such, while some aspects of the supercompensation model, primarily biochemical, have been demonstrated (Jentjens & Jeukendrup, 2003), the supercompensation model remains a conceptual framework. The simplifications inherent in the model means there is no differentiation of individual responses, nor between the effects of different intensities and types of training stimuli. Some of these issues have been discussed and critiqued by researchers from the perspective of how supercompensation underpins periodisation theory (Issurin, 2010; Kiely, 2018).

An alternative theory, the fitness-fatigue model (Figure 4) has been proposed in an effort to better explain the relationship between fatigue and fitness (Banister et al., 1975). In the

fitness-fatigue model, both fitness and fatigue occur in response to training, and the intensity of the training stimulus effects both the degree of fitness and fatigue. Although various definitions exist, fatigue has been defined as a "failure to maintain the required or expected force" (Edwards, 1983). The difference between these fitness and fatigue components describes the preparedness of the athlete. Intensified training means that fatigue masks fitness levels, and conversely, a programmed taper can reduce fatigue levels to uncover fitness (Fitz-Clarke et al., 1991; Hellard et al., 2006). This model is described by differential equations, with the result that an athlete's performance can be mathematically modelled (Pfeiffer, 2008).

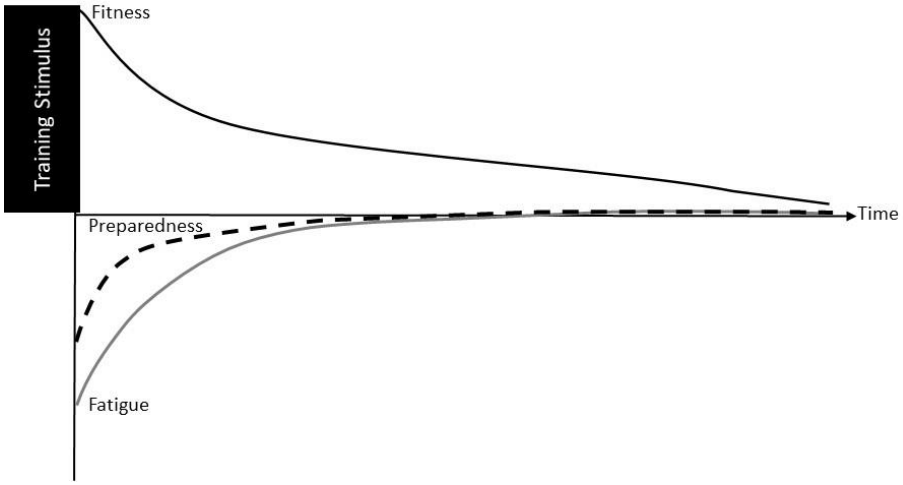

Figure 4. Fitness-Fatigue theory where the summation of fitness and fatigue determines an athlete's preparedness (adapted from Zatsiorsky & Kraemer, 2006).

The fitness-fatigue and supercompensation models have conceptual similarities. However, the fitness fatigue model advances our understanding of the training response by the addition of a two- component model and the ability to model and individualise training responses (Fitz-Clarke et al., 1991). This is in comparison to the more simplified cause and effect model shown in Figure 3 (Bompa, 1999; Selye, 1950; Yakovlev, 1955). Therefore, in order to optimise performance gains, understanding the relationship between the key parameters of fitness, fatigue and performance is essential to help determine the efficacy of a training programme and the subsequent individual performance effects (Bompa, 1999). This is particularly true in the elite environment where elite athletes are subject to high training loads, limited recovery periods and are more at risk of negative performance or health outcomes (Halson, 2014). Athlete monitoring systems are a method that, when correctly employed, can aid understanding of these relations.

Despite the importance of an athlete's balance of fitness, fatigue and recovery, for performance enhancement and injury/illness prevention, no single measure has been

identified that can comprehensively reflect an athlete's fitness or fatigue status (Borresen & Lambert, 2009). There is also no agreement around the best method to quantify training load for a given sport (Bourdon et al., 2017). These issues can therefore make it challenging to assess the relative training status of an athlete in relation to their fitness/fatigue (see Figure 3, Figure 4) Therefore, unless addressed, the uncertainty around selecting appropriate athlete monitoring and training load measures can make it difficult to determine what metrics to include in an AMS. Researchers have also highlighted various barriers to implementing AMS (Saw et al., 2015b). Some of these areas of concern included poor end-user buy in to an AMS and a lack of sports specificity of the measures. Taken together these uncertainties surrounding the content and barriers to AMS implementation may derail the best intentioned AMS (Saw et al., 2017). Strategic methods to overcome these issues, which are also practical and feasible in the elite applied world have yet to be fully explored.

As the use of AMS is widespread (Taylor et al., 2012), and their positive impact on performance and illness/injury has been arguably demonstrated (Drew & Finch, 2016), this literature review explores issues related to AMS practices and implementation in elite sport. Given the political climate around elite athletes' health (Ingle, 2018; Roan, 2018), such research is also particularly timely. Accordingly, this review will critique the monitoring tools that are commonly used in elite sport, and current trends and issues relating to these measurements.

2.1.1 Athlete Monitoring Systems

Athlete monitoring systems in elite sport monitor and track a range of subjective and objective measures that relate to performance and the fitness or fatigue status of an athlete e.g. RPE, speed, or heart rate (Halson, 2014). The form an athlete monitoring system takes can vary, but typically practitioners in elite sport reportedly use a mix of off-the-shelf or custom software and/or Excel spreadsheets to collect their data (Akenhead & Nassis, 2016; H. R. Thornton et al., 2019). The scientific rigour of any AMS is primarily dictated by the metrics it uses (Saw et al., 2017). Research has demonstrated significant use of athlete monitoring metrics which are customised by the users (Taylor et al., 2012). Custom metrics are defined as measures that those within a sporting organisation have crafted themselves, their scientific validity is often unknown, and their results are not readily available in published research. Therefore, it is important to consider the concept of scientific rigour and validity in relation to AMS in elite sport, and this is discussed in more detail below.

Validity can be defined in as the accuracy of a measure i.e. does the metric measure what it is designed to measure (Gratton & Jones, 2010). There are several different types of validity:

content validity considers whether a tool is appropriate to assess the parameter it aims to measure. Face-validity considers whether the tool superficially appears to measure what it purports to measure. Construct validity considers whether or not a measurement tool reflects the underlying theory and therefore measures the correct or intended parameter (Currell & Jeukendrup, 2008; Field, 2013). Finally, criterion validity considers the relationship between the measurement tool and other measures.

For the purposes of this thesis, the term 'validity' is used as an umbrella term to refer to all of these parameters, but usually with an emphasis on construct validity, as this has been shown to be important for psychometric tests (Hughes, 2017) and is arguably the most rigorous form of validity (Field, 2013; Gratton & Jones, 2010).

2.1.2 Current Athlete Monitoring Trends in Elite Sport

While there have been multiple studies regarding AMS in elite sport (Buchheit et al., 2013; Burgess, 2017; Veugelers et al., 2016), researchers have tended to address monitoring trends only within a single sport. Consequently, there appears to be a lack of systematic insight into the broader landscape and patterns in AMS across a range of elite sports. This dearth of information can inhibit the sharing of best practice, the advancement of research, and an understanding of whether AMS research is proving useful in the elite sport setting. Perhaps however, given the backdrop of a 'global sporting arms race' (De Bosscher et al., 2008), this lack of insight into athlete monitoring trends in elite sport is unsurpising, as arguably it results from privacy and confidentiality issues surrounding a country or sporting organisation's intellectual property.

While there is a paucity of research that critically analyses current AMS practices across elite sport, it is possible to gain an indirect insight into current monitoring trends through the athlete monitoring measures employed in research. Two systematic reviews have examined the relations between markers of athlete health and how they are impacted by training load (C. M. Jones et al., 2017; Saw et al., 2015c). These articles reviewed the research trends in over 100 peer-reviewed articles in trained through to elite athletes. Alongside these review articles, Taylor et al. (2012) examined cross-sport trends in training monitoring in elite sport in Australiasia. These articles have been analysed (see Figure 5) to give an insight into the trends in athlete monitoring in relation to fatigue or illness measurement across a broad array of sub-elite to elite athletes in individual and team sports. This therefore allows comparison between methods embedded in applied practice (Taylor et al., 2012) and research (C. M. Jones et al., 2017; Saw et al., 2015c). The measures analysed were grouped into athlete self-report

questionnaires, fitness and performance tests, and various cardiovascular and biochemical parameters, which are discussed in more detail below.

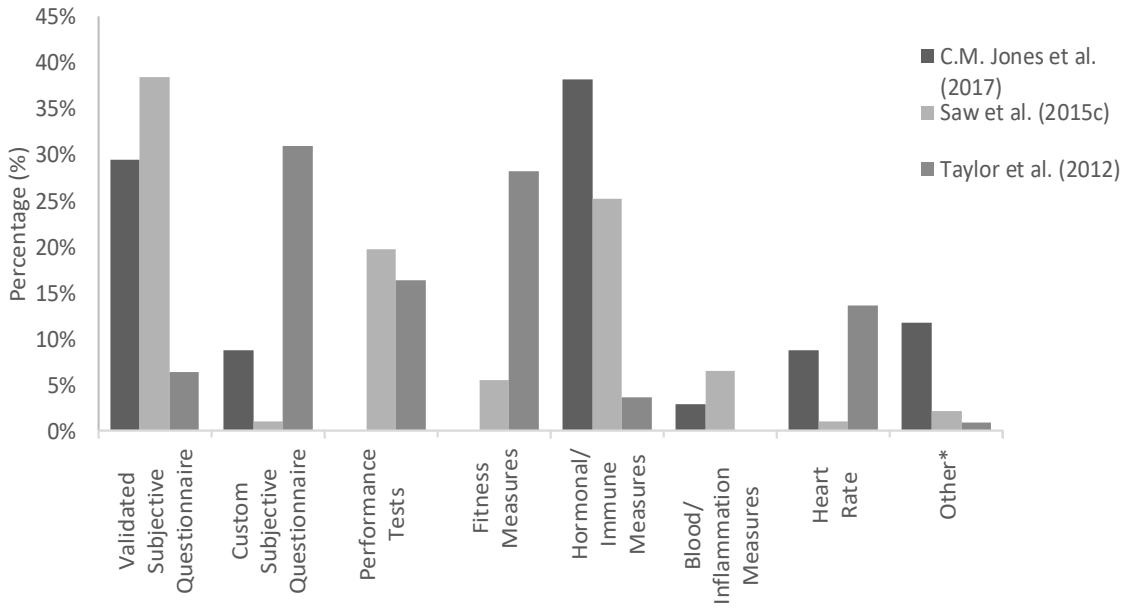

Figure 5. Use of athlete monitoring measures in research studies in elite and sub-elite athletes from three different research articles.

Data normalised to percentages to allow comparisons between articles. Research is presented from 67 peer-reviewed articles from data mined in Jones et al. (2017), where fatigue was compared to illness/injury data, and Saw et al. (2015c). The elite sport environment is reflected in the results from 50 elite sport respondents, presented by Taylor et al. (2012). The data is expressed as a percentage of the total frequency reported in each article. *Other includes measures of resting blood pressure, musculoskeletal screening, hydration status and objective markers of sleep.

Figure 5 illustrates the use of custom subjective questionnaires is more prevalent in elite sport practice (Taylor et al., 2012) than validated subjective questionnaires use, and the use of validated subjective questionnaires is more prevalent in published research (C. M. Jones et al., 2017). Validated subjective questionnaires are defined for this purpose as athlete self-report questionnaires or measures which have been published and reviewed for their validity e.g. REST-Q or ARSS (Kellmann & Kallus, 2016; Kölling et al., 2020). Arguably, custom questionnaires have reduced scientific rigour and credibility, this issue may therefore make it more challenging, and thus less attractive, to publish research articles which involves them (Byrne, 1998), and may explain the trends observed in Figure 5. Consequently, the results indicating fewer research publications utilising custom subjective questionnaires may, in part, be a function of the publication process, rather than being reflective of actual practice in elite sport.

Perhaps more important is to understand why there appears to be a trend for elite sports to implement custom subjective questionnaires over validated questionnaires. Understanding the reason for the extensive use of custom questionnaires in elite sport is important as their lack of scientific rigour may result in missing meaningful changes in athlete health, or a failure to identify preventable illnesses/injuries, thus negatively affecting athlete health and, potentially, athletic performance (Saw et al., 2017). Some of the reported reasons for the poor uptake of validated questionnaires is their lack of sports specificity (Taylor et al., 2012). It has been argued that a lack of sports specificity in validated questionnaires risks the measures becoming irrelevant in the eyes of the coach (Saw et al., 2015b). It is however important to note that it does not follow that increased sports-specificity equals increased measure sensitivity (Ekkekakis, 2011). Other reasons for the poor uptake of validated questionnaires includes their often extensive, and thus time-consuming nature rendering them impractical (Taylor et al., 2012).

Other barriers to the use of validated questionnaires maybe inferred from examining similar issues in the allied field of health. In health research, there is a push towards empowering individuals to make positive health choices through improving health literacy and thus their ability to adhere to prescribed interventions (Nutbeam, 2000). However, where health literacy is poor, the effectiveness of education as an intervention to change undesirable health habits is negatively affected (Nutbeam, 2000). Similarly, in elite sport it could be argued that if practitioners and coaches do not fully comprehend the advantages and disadvantages of validated and un-validated questionnaire use, custom questionnaire use with unknown validity may continue. Sports science managers (SSM) should therefore ensure that staff members are up-to-date on the pros and cons of validated versus custom questionnaires, and establish a path to ensure confidence in any custom measures employed. Saw et al. (2017) addresses the issue of questionnaire validity, and provides useful guidance for SSM on how to address these concerns.

Recently, custom questionnaires have been argued to demonstrate good measure sensitivity i.e. measure accuracy (Burgess, 2017), which is a facet of construct validity (Impellizzeri & Marcora, 2009). However, the articles referenced as evidence to support this claim (Buchheit et al., 2013; Gastin et al., 2013; Montgomery & Hopkins, 2013) employed different custom athlete self-report questions, with differing response scale lengths over varying time courses and training phases. The sports tested were also limited to football and Australian rules football. The argument that custom questionnaires are sensitive does not therefore appear to be generalisable to wider cohorts of elite athletes. Further, while none of the studies referenced by Burgess (2017) had a primary aim of testing validity of their measures, good reliability and sensitivity of 5-point visual analogue scales (Gastin et al., 2013) and 5 and 10-point Likert scales

were demonstrated (Buchheit et al., 2013; Montgomery & Hopkins, 2013). Arguably however, the use of coefficient of variations or typical error to assess the reliability of Likert scale responses in these papers is flawed as the data is ordinal (Field, 2013). Overall, while these insights into the use of custom questionnaires are encouraging and demonstrate face validity, they do not conclusively support the use of custom questionnaires outside of the context reported in these articles; nor does the assertion that custom questionnaires are valid appear to be based upon a strong scientific foundation. Accordingly, such statements should be viewed with caution. Consequently, while both the utility and extensive use of custom questions on athlete wellness in elite sport has been demonstrated (Gastin et al., 2013; Saw et al., 2015c; Taylor et al., 2012), there has been little focus on validating this approach, perhaps as a result of the unique design of each questionnaire. Further research in this area is warranted to allow practitioners to employ wellness questions with confidence and greater scientific robustness.

Fitness and performance testing are both common AMS measures, both in applied elite sport and published research (see Figure 5). Sustained decrements in performance are a key indicator of athlete maladaptation, and it is therefore logical to use both fitness and performance indicators within an AMS (Meeusen et al., 2013). In Figure 5, the term 'performance test' was used to indicate an all-out effort, usually closely replicating the athlete's event, e.g. a 40-km cycling time trial. The term 'fitness measure' encompassed tests that measured subsections or allied components of that performance, e.g. vertical jump or $\dot{V}O_{2max}$. The use of fitness measures or performance tests appears routine in both the elite sport environment and research, with the use of fitness measures in particular more prevalent in elite sport (Taylor et al., 2012). Furthermore, there is evidence that performance measures are key factors used by coaches to inform their decision making (Pope et al., 2018), and should therefore be considered for inclusion in AMS.

Performance tests can however be time-consuming to administer, and testing can interfere with normal training (Halson, 2014; Saw et al., 2017). As such, the differences between performance/fitness testing frequencies in published research and elite sport (Figure 5), could be a result of limited opportunities for practitioners to, 'performance test' athletes. Practitioners may instead use fitness tests as a proxy measure. Conversely, as reflected in Figure 5, performance tests were the test of choice in published research, likely as a result of performance being a desirable metric, and the highly structured and controlled conditions that researchers are able to apply to their work in comparison to the applied setting (C. M. Jones et al., 2017; Saw et al., 2015c). Nonetheless, despite elite sports subscribing to both fitness measures and performance testing as a method of monitoring athlete health, published information regarding

the frequency of test administration and type of test administered is not always readily available, perhaps due to intellectual property concerns (C. M. Jones et al., 2017; Saw et al., 2015c; Taylor et al., 2012).

There is little reported use of biochemical measures (see Figure 5) such as hormonal, immune, blood and inflammation measures in elite sport (Taylor et al., 2012). This is a stark contrast to published research, where authors use these measures extensively (C. M. Jones et al., 2017; Saw et al., 2015c). Reasons for this disparity could be due to regular biochemical monitoring being impractical or cost-prohibitive to the sporting organisation (Halson, 2014). Additionally, if the sport lacks the personnel with expertise in administering biochemical testing, or encounters difficulties in achieving buy-in with stakeholders, implementation of this type of testing regimen may be unfeasible (Saw et al., 2017). Consequently, the use of biochemical measures may be better suited to defined research project work, perhaps where athlete health is a cause for concern, or until such time as the sporting body has the necessary time, equipment and skilled personnel to deliver biochemical testing.

The reported infrequent use of biochemical measures in applied elite sport is however surprising given that medical checks for elite athletes usually occur annually and typically involve a complete blood count (Ljungqvist et al., 2009). Accordingly, it is possible that biochemical testing is being administered semi-regularly in elite sport, but as sports medicine doctors did not participate in the survey analysed (Taylor et al., 2012), this information may not have been captured. Additionally, this presumed oversight of biochemical data may also be attributable to complete blood count data and other medical information being kept in a separate data silo, to which practitioners may not have access (Halson, 2014).

Blood pressure, musculoskeletal screening, hydration and sleep status were reportedly sparsely used as athlete monitoring measures in both published research and the elite sport environments (see Figure 5). This made no discernible patterns in the use of these measures apparent between applied practice in elite sport and published research; however, some of these areas, specifically the objective measurement of sleep, have become more accessible and popularised with the rise of activity trackers, and so these trends may change in the near future (Gupta et al., 2016). There are numerous studies on heart rate measures, from heart rate variability through to resting, recovery and submaximal heart rate in the literature (Daanen et al., 2012; Plews et al., 2013), however in elite sport practice it appears heart rate measures are primarily used to assess submaximal exercise testing, rather than using heart rate at rest or heart rate variability (Taylor et al., 2012). This apparent reticence to apply more diverse methods of

heart rate monitoring could perhaps be attributed to equivocal findings in this area, and the frequency and time that is required to analyse heart rate variability data (Bosquet et al., 2008; Buchheit, 2014).

Until more data is published on the monitoring measures used in elite sport, insights into current practice can only be gained through comparisons of trends in research articles such as those shown in Figure 5 e.g. (C. M. Jones et al., 2017; Saw et al., 2015c) and a descriptive study of the methods used across a variety of Australasian elite sports that is now eight years old (Taylor et al., 2012). In order to better address the demands of the elite sport environment, much additional research is therefore needed to allow researchers to identify where and why the transfer of published research into elite sport practice has not been successful.

Overall it appears that athlete monitoring trends within applied elite sport tend towards solutions that are intuitive, practical, non-invasive, and require limited analysis and buy-in from stakeholders within the sport (Roos et al., 2013; Taylor et al., 2012). Understandably, this approach aims to minimise the disruption to training that monitoring can incur, while seeking to preserve and optimise athlete health and performance. The balance between practicality and scientific rigour in elite sport appears to be heavily weighted towards the former, which, as previously discussed, risks missing meaningful changes in athlete monitoring data (Saw et al., 2017). Conversely, published research has a much more mechanistic approach, seeking to establish patterns and relations between variables, whilst ensuring that studies conform to established norms underpinned by scientific theories.

The dichotomy between published research and applied practice is perhaps a result of serving the differing environments they reside in: either to win medals, at almost any cost (De Bosscher et al., 2008), or to 'publish or perish', with research direction frequently dictated by government policies or funding bodies, rather than the needs of elite sporting organisations (Rawat & Meena, 2014). The competing demands of these different worlds makes it challenging to bridge the gap between them (Coutts, 2017).

While the data from Taylor et al. (2012) furthers our knowledge of the AMS practices in elite sport, fundamental questions still remain on the efficacy of current practice. Recent research has provided little insight into why is particular measures are recorded, and, to date, no similar analyses of athlete monitoring practices in the UK have been published outside of premiership football (Akenhead & Nassis, 2016; Weston, 2018). Understanding the reasons behind the AMS employed, and the quantitative and qualitative perceptions and indicators of efficacy would

further enhance our understanding of strengths and weaknesses in this research area, particularly with reference to elite amateur sport in the United Kingdom.

2.2 Over-training

When there is an imbalance between training volume, intensity, and recovery, athletes can become over-reached or over-trained. Typically this results in performance decrements, with the possibility of clinical or sub-clinical symptoms presenting (Meeusen et al., 2013). The defining feature of over-training syndrome is a long-term decrement in performance, which can take months or more to recover from. A joint consensus statement (Meeusen et al., 2013) outlined a continuum of over-training which is summarised in Table 1.

Table 1. Possible presentations of the different stages and progression of functional overreaching to over-training syndrome (adapted from Meeusen et al., 2013).

Process	**Training**	⟶	**Intensified Training**	⟶
Outcome or status	Acute Fatigue	Functional Over-reaching	Non-Functional Over-reaching	Over-training Syndrome
Recovery time	Day(s)	Days - Weeks	Weeks - Months	≥ Months
Performance	Increase	Temporary Decrease	Decrease	Decrease

An AMS aims to identify athlete maladaptation, which could lead to over-training through the use of robust and evidence-based measures of athlete training status (Bourdon et al., 2017). Unfortunately, a lack of consistent terminology and definitions surrounding over-training and a broad array of individual differences in presentation has reduced the clarity of its aetiology. Furthermore, no definitive diagnosis for over-training syndrome exists (Lewis, Collins, et al., 2015). These problems have compounded to complicate the interpretation and correct diagnosis of overreaching and over-training, making it challenging to understand which parameters should be included in an AMS in order to indicate athlete maladaptation.

A range of terms have been used to describe what has been commonly termed as over-training: this includes staleness (Kellmann, 2002), burnout (Morgan et al., 1987) and training stress (Urhausen et al., 1995). Given over-training syndrome can have causes other than excessive training, there is the potential of this term being a misnomer. Consequently, the alternative term Unexplained Underperformance Syndrome has been proposed (Budgett et al., 2000). To date, however, the lexicon within elite sport, and most of the research literature, continues to use the term over-training, and therefore, for the purposes of this thesis, the term over-training is used (Lewis, Howatson, et al., 2015). While the current terminology use is

arguably flawed, its status-quo may be justifiable until more clarity can be gained concerning the clinical diagnosis of over-training (Lewis, Collins, et al., 2015). However, practitioners and medical personnel risk being misunderstood by athletes and coaches if they fail to unify their vocabulary, and thus clarify the potential multifactorial aetiology of over-training syndrome.

2.2.1 Incidence of Over-training in Elite Sport

High incidence rates of over-training of approximately 10% (range 7–21%) have been reported in senior elite athletes (Koutedakis & Sharp, 1998; Meeusen et al., 2013; Raglin & Wilson, 2000). However, evidence from British Cycling indicated over-training was largely absent from their athletes, perhaps as a result of sufficient sport science and medicine support (Lewis, Collins, et al., 2015). Nonetheless, it appears that over-training is a threat to elite athletic performance due to the periods of intensified training athletes are exposed to; therefore, processes to mitigate this, such as robust monitoring, can aid identification of maladapted athletes (Halson, 2014).

Risk factors for athletes becoming over-trained include: being male (Koutedakis & Sharp, 1998), being an individual sport athlete (Matos et al., 2011), being in the pre-competition/competition phase of the season (Koutedakis & Sharp, 1998) and being internationally successful (Meeusen et al., 2013). Other risk factors include altered environmental conditions, including altitude and heat, sleep loss, personal difficulties and poor nutrition, specifically a prolonged reduced energy availability or negative energy balance (Lewis, Howatson, et al., 2015; Meeusen et al., 2013).

Why certain groups appear at a more elevated risk of over-training syndrome than others is still not entirely clear. Further, methodological differences between research papers exacerbates this issue. However, a range of multi-factorial causes, including predisposing psychological and physiological characteristics have been hypothesised (Halson & Jeukendrup, 2004; Koutedakis & Sharp, 1998; Meeusen et al., 2013). While further research is required, this information may help practitioners to profile which of their athletes may be at most risk from over-training syndrome and when this may occur in the training calendar. More importantly, this underlines the importance of careful and individualised athlete monitoring, perhaps periodized to the training calendar, to support early diagnosis of athlete maladaptation.

2.2.2 Diagnosis

There is no definitive diagnostic criteria for over-training or non-functional over-reaching (Lewis, Collins, et al., 2015). This poses difficulties in constructing robust AMS measures, as over-training is investigated through exclusion analysis. Correct diagnosis is further complicated by significant individual differences in clinical presentation and a failure to

establish typical measures and standards for over-training syndrome (Lewis, Collins, et al., 2015).

Despite these issues, there is some agreement on the normal markers of over-training syndrome, beyond the expected decrements in performance and increased recovery requirements (Aubry et al., 2014). The broadly recognised indicators include: psychological changes, abnormal changes in RPE (rating of perceived exertion), heart rate, hormonal measures, redox homeostasis, biochemical markers, and an increase in infective illness rates (Armstrong & VanHeest, 2002; Lewis, Howatson, et al., 2015; Meeusen & De Pauw, 2019; Urhausen & Kindermann, 2002). These measures can be split into two types: objective and subjective. Historically, the literature has focussed on the former (Balsalobre-Fernańdez et al., 2014; Buchheit, 2014); recently, however, the latter has gained popularity (Saw et al., 2015c). Elite sport normally uses a blend of the two to assess the status and health of athletes (Taylor et al., 2012).

Despite the presence of numerous validated measures of training status in the published literature (Bourdon et al., 2017), elite sports frequently use un-validated measures of training status, particularly self-report questionnaires (Gastin et al., 2013; Taylor et al., 2012). This is reportedly due to the impracticality of validated measures, their often burdensome nature, and their lack of sport specificity, which confounds stakeholder engagement. Where un-validated measures are used, a lack of underpinning scientific rigour could lead to a failure to detect meaningful change in training status or athlete health (Halson, 2014; Saw et al., 2017). Ironically, the short-term gains in stakeholder engagement that custom AMS provide, may, in the longer term, be outweighed by end-user disillusionment indifference or inaccuracy of the metrics, if the AMS does not meet expectations or its stated purpose (Saw et al., 2015b).

In the case of either custom objective or subjective measures, it is beyond the scope of this review to assess their utility. Moreover, it is unlikely that elite sports will publish information pertaining to any custom measures due to intellectual property concerns. Consequently, this review will focus on validated measures that have been reported in the literature, and that are also known to be used in elite sport (Taylor et al., 2012).

2.2.4 Relative Energy Deficiency Syndrome (RED-S) and Over-training

An IOC consensus statement (Mountjoy et al., 2014), proposed replacing the term female athlete triad with Relative Energy Deficiency in Sport (RED-S). This change was made to extend the diagnostic criteria of the female athlete triad and to include both males and a wider array of pathologies, it has however proved contentious (De Souza et al., 2014).

It is important to note that there is a significant amount of overlap between the symptoms associated with RED-S and those seen with over-training syndrome. RED-S has been defined as impaired physiological functioning resulting from a relative energy deficiency presenting with potential multi-factorial symptomology (Mountjoy et al., 2014); whereas, over-training is a long-term decrement in performance resulting from intensive training and insufficient recovery (Meeusen et al., 2013). As indicated elsewhere (Lewis, Collins, et al., 2015) chronic energy deficiencies have been noted in cases of over-training. It is, therefore, difficult to infer whether RED-S is a possible consequence of athlete maladaptation, or a cause of it. Either way, this overlap in symptomology has received very little attention, and it is unclear whether RED-S forms part of the diagnostic criteria for over-training, or whether the two are mutually exclusive conditions.

While further research is needed to untangle the differences, if any, that occur between RED-S and over-training, it appears logical that indicators of RED-S, such as body composition or nutritional status may be valuable measures to include within an AMS.

2.2.5 Performance, Recovery and Illness/Injury

Undesirable changes in performance are one of the clearest markers of athlete maladaptation alongside increased recovery requirements (Table 1). While some debate exists on the most representative performance test to detect changes in performance (Halson & Jeukendrup, 2004), sports-specific time trials, time to fatigue tests, and short-duration high intensity tests preceded by a short rest have been reported to be the most sensitive and reliable (Meeusen et al., 2006, 2013; Urhausen & Kindermann, 2002). Arguably, however, the best measure is in-competition performance itself, with decrements of >1% suggested to be a significant finding (Halson & Jeukendrup, 2004).

To aid assessment of meaningful performance fluctuations, measures of performance across the season can provide a useful insight into unexpected performance decrements. The collection of a performance profile across a season can however be a challenge to accumulate in the elite environment, with opportunities to capture this information limited due to training and competition requirements (Currell & Jeukendrup, 2008). To ensure continuity of a training plan, it may not be possible to plan a rest period prior to a performance assessment as it may negatively affect the performance (Bosquet et al., 2007). Accordingly, frequent benchmark training sessions (Burgess, 2017; Taylor et al., 2012) or use of individual speed thresholds (Abbott et al., 2018), may prove a viable alternative for the applied practitioner to assess training status, and should be considered for inclusion in an AMS, if regular performance testing is not possible.

Recovery requirements in maladapted athletes increase as shown in Table 1; Meeusen et al. (2013). Accordingly, recovery is a multidimensional construct which can and should be monitored to assess training status (Heidari et al., 2018). Some of the indictors of recovery are discussed in more detail below, but typically these include parameters such as athlete self-report measures on recovery and fatigue status (Saw et al., 2015c), heart rate monitoring (Buchheit, 2014) or biochemical markers (M. R. McGuigan, 2017).

An increase in infective illness rates, particularly upper respiratory tract infections (Lewis, Collins, et al., 2015), has been noted in over-trained athletes. This is thought to be related to suppressed immune function (L. L. Smith, 2003). Over-trained athletes are also noted to be at an increased risk of injury, potentially mediated by a chronically reduced energy availability, allied to RED-S (Mountjoy et al., 2014). As, arguably, a link between illness, injury and excessive training loads has been established (Drew & Finch, 2016), logging the aetiology and duration of illnesses and injuries should be a fundamental part of an AMS. Such information is typically recorded by the medical side of the MDT (Halson, 2014); however, for various reasons, including data protection, confidentiality (General Medical Council, 2013), historical convention, or practicality, the data is often kept separately from day to day athlete monitoring information (Halson, 2014). Where this occurs, there is a risk that data silos result in a lack of joined up thinking, potentially with the result that athlete maladaptation is missed. It is therefore important that pertinent medical information is shared within the MDT, where confidentiality permits, and/or that it is integrated into the AMS (Dijkstra et al., 2014).

2.3 Psychological and Self-Report Measures for Monitoring Athletes

Athlete self-report measures explore key areas such as an athlete's mood disturbances, need for recovery, cumulative training stress and current life circumstances. Athlete maladaptation or over-training syndrome is associated with negative psychological changes, which athlete self-report measures aim to capture (Saw et al., 2015c). As athlete self-report measures are typically cheap and easy to deploy, they are regularly used in elite sport (Taylor et al., 2012). Consequently, practitioners need an understanding of which questionnaires may be suitable for their sporting organisation.

Validated questionnaire tools that are often referred to in elite sport research include the Daily Analysis of Life Demands for Athletes (DALDA), Profile of Mood States (POMS), the Recovery Stress Questionnaire for Athletes (REST-Q), and more recently the Acute Recovery and Stress Scale (ARSS) (Kellmann & Kallus, 2001; Kölling et al., 2020; Lorr et al., 1971; Nässi et al., 2017; Rushall, 1990). These questionnaires have all been validated, and are capable of highlighting under-recovery in elite cohorts of athletes (Halson, 2014; Saw et al., 2015c).

POMS has been widely used and validated in research (Leunes & Burger, 2000; Prapavessis, 2000) but it's utility in the applied sport setting is often questioned, as it was originally developed for clinical settings (Nässi et al., 2017). As it comprises 65 questions on an anchored 5-point Likert scale, its length can also make it impractical for daily use. Shortened validated versions of POMS that have been used in sport are however available which, given the time constraints in elite sport, might be more appropriate for use in this setting (Faude et al., 2011; Shacham, 1983).

While POMS was not initially developed with sporting populations in mind, both DALDA and REST-Q were. DALDA, somewhat uniquely, examines both the sources and symptoms of stress over 34 questions, with a scale that compares each parameter in respect to normal (Rushall, 1990). As elite athletes are frequently 'over-reached,' the approach of comparing today to 'normal' may prevent reinforcing their fatigued state, an issue that has been reported previously (Saw et al., 2015b). DALDA has been critiqued for not allowing statistical analysis of the dataset (Nässi et al., 2017), as no scores or scales are attributed to the results. As questionnaire responses are usually categorical in nature, or use Likert scales, applying quantitative statistical analysis, such as means, has been deemed an inappropriate method of analysis (Jamieson, 2004; Saw et al., 2017); however, some authors argue against this stating that Likert scales can be treated as interval data (Carifio & Perla, 2007) and such approaches are observed in the literature (Gastin et al., 2013). In comparison to DALDA, REST-Q has 76 items on a 0 to 6-point anchored Likert scale that focusses on different elements of stress and recovery (Kellmann & Kallus, 2001). Similar to POMS, its length renders it unfeasible for regular use; however, a shorter version has recently been published that may be more appropriate for use in the elite sport setting, although further investigation to assess its validity is required (Kellmann & Kallus, 2016; Nässi et al., 2017).

These validated questionnaires have various similarities that are indicative of best practice in this area, including anchored scales (ranging from 3 to 6 points), and specified timeframes for which the athletes are required to report their results. While the content of the questionnaires varies, there are some commonalities, such as questions on fatigue, recovery, physical symptoms, being in shape, and general wellbeing. It is these subscales that have been shown to be the most sensitive to changes in acute or chronic training loads (Nässi et al., 2017; Saw et al., 2015c), which, accordingly, practitioners may want to closely monitor as part of their AMS. Conversely, measures such as depression, confusion, emotional stress and sleep quality have been reported as unresponsive to changes in training load, and their inclusion in an AMS should therefore be carefully considered (Saw et al., 2015c). Collapsing all scores from a given

questionnaire into one umbrella score appears to reduce the sensitivity of the measures and should be avoided (Saw et al., 2015c).

Contradictory findings have however emerged on the utility of sleep measurements as a method to assess the training status of an athlete. Sleep is essential for recovery, both mentally and physically from training (Lastella et al., 2018), and sleep disturbances have been linked to the early stages of athlete maladaptation (Kellmann, 2010; Urhausen & Kindermann, 2002). The findings that sleep is unresponsive to training load (Saw et al., 2015c) therefore conflicts with these findings and appears illogical. This issue may instead be explained by methodological problems with the REST-Q sleep subscale analysed by Saw et al. (2015c) as it has been previously shown to lack validity and have poor reliability (Davis IV et al., 2007). Advances in the technological capabilities of measuring sleep at home via actigraphy (Leeder et al., 2012), may instead provide alternative methods to assess sleep quantity/quality.

Several different and validated athlete self-report measures exist (Coutts et al., 2007; Kellmann & Kallus, 2001; Lorr et al., 1971). However, of 50 participants in Australian high performance sports surveyed (Taylor et al., 2012), 80% reported using custom built athlete self-report measures, rather than published and validated questionnaires. If this trend is similar in the UK, a dichotomy between research and practice exists which may have negative connotations for the effectiveness of an AMS if the validity of the customised metrics has not been established (Buchheit, 2017). Guidelines aiming to bridge this gap (Saw et al., 2017), and some of the best practice approaches outlined above, may support practitioners choosing to use custom athlete self-report measures over validated measures

RPE is a widely used measure of training intensity in elite sport that athletes self-report (Halson, 2014; Taylor et al., 2012). RPE is cheap, intuitive, applicable to different exercise modalities, widely validated for measuring internal training stress and thus an indirect indicator of athlete health (Burgess, 2017). Various different RPE scales exist, and research has provided some guidance for their selection and use (Scott et al., 2013). The use of RPE does however present some problems, as both familiarisation and the timing of administration are important for reliability purposes (Wallace et al., 2009). Further, differences have been reported between coach predicted RPE and athlete perceived RPE for a given session (Murphy et al., 2014), with a trend for athletes to work too hard on sessions that are intended to be easy and too easy on sessions that are intended to be hard (Haddad et al., 2017; Scott et al., 2013). Overall however, when these methodological concerns are addressed it appears that RPE can provide practitioners with some meaningful insights into how athletes respond to training (Wallace et al., 2009).

2.4 Biological Measures for Monitoring Athletes

A range of physiological and biochemical markers are thought to give indications of athlete training status (Heidari et al., 2018). A summary of some of those most pertinent markers known to be either widely used in applied elite sport or frequently cited in published research are discussed below (see also Figure 5).

2.4.1 Heart Rate

Maximal heart rate, submaximal heart rate and heart rate recovery are measures that are relatively easy and inexpensive to employ, and give objective data regarding the internal training load on an athlete (Burgess, 2017). While heart rate measures are known to be employed in elite sport (see Figure 5), the use of measures such as submaximal exercising heart rates have been reported to be more commonly used than heart rate variability, or heart rate at rest (Taylor et al., 2012). This is surprising given the ease with which heart rate measures can be administered, but while heart rate variability shows promise in providing useful insights into an athlete's fitness/fatigue status, equivocal findings suggest that it should, pending further research, be used with caution (Meeusen et al., 2013). Using a weekly rolling average of the natural logarithm of the square root of the mean sum of differences squared between R–R intervals (Ln rMSSD) may provide the most reliable measure for practitioners (Plews et al., 2013). While low-cost to administer, this method is however labour intensive as it requires longitudinal commitment from the athlete and analysis of significant volumes of data, to establish individual norms. As such sporting organisations should consider whether the use of heart rate variability as an athlete monitoring metric is practical or scalable to their squads.

2.4.2 Biochemical Measures

Research has provided a slew of possible biochemical measures, encompassing hormonal, immunological and blood parameters that can indicate training status with varying degrees of accuracy. As only a small subsection of biochemical measures appear to be regularly used in elite sport (Taylor et al., 2012), a few of these key parameters are discussed below.

Reduced submaximal and maximal lactate concentrations have been noted in non-functional over reached and over-trained athletes (Urhausen & Kindermann, 2002), believed to be the result of glycogen depletion (Meeusen et al., 2013). However, conflicting findings have also been reported, where no statistically significant changes in lactate have been found in maladapted athletes (Halson & Jeukendrup, 2004). These differences could be explained by either a lack of dietary controls (Purvis et al., 2010) or failing to attain statistical significance where changes in lactate are only slightly larger than measurement error. It might therefore be more appropriate to analyse lactate results using smallest worthwhile change statistics

(Hopkins, 2000) rather than traditional '*p*-value' statistics. Confusingly, reduced lactate concentrations can also be an indicator of improved performance (Jones & Carter, 2000) and so this variable should not be used alone to denote maladaptation.

Some parameters, such as creatine kinase, salivary IgA, leucocytes, testosterone cortisol ratio, glutamine: glutamate ratio and cytokines (Il6) are thought to change in response to intense exercise (Lewis, Collins, et al., 2015; Purvis et al., 2010). However, there is currently insufficient evidence that these measures can distinguish maladaptation from a heavy training bout. Nor is it believed that these biochemical parameters allow overreaching to be differentiated from over-training (Halson & Jeukendrup, 2004; Lewis, Collins, et al., 2015). In addition, individual variability, the diurnal or seasonal variability of some parameters and differences in assays has led to inconsistent findings, making it unclear which markers to select for an AMS (Lewis, Collins, et al., 2015).

Measuring redox homeostasis (a disturbance in the balance of oxidants to antioxidants) has been suggested as an alternative way to monitor elite athletes' response to training (Lewis, Howatson, et al., 2015). While results in this area look promising, this is an emerging area of research that, to date, has only been applied to endurance athletes (Lewis et al., 2018). While a change in redox homeostasis is apparent in maladapted athletes, the exact relationship between over-training and redox homeostasis has yet to be elucidated.

2.5 Training Load

Measures of training load are frequently incorporated into AMS (Taylor et al., 2012) as they are arguably considered predictive of illness and injury risk (Drew & Finch, 2016; Gabbet, 2016; Hulin et al., 2014). Common examples of training load quantification include session RPE (sRPE), where training duration is multiplied by RPE (Foster et al., 2001), measurement of external work, e.g. distance covered via GPS (Burgess, 2017), training impulse (Banister et al., 1975), and acute to chronic workload ratio (Hulin et al., 2014).

While each method has its advantages and limitations, sRPE is the only measure that can be applied across all exercise irrespective of modality, without the validity issues that come with heart rate at supramaximal or interval exercise (Borresen & Lambert, 2009) or managing large datasets with GPS data (Passfield & Hopker, 2017). Session RPE is also a cheap and relatively easy method to apply once users have been habituated to the RPE scale. For these reasons, despite its subjective nature, sRPE is popular in elite sport (Algrøy et al., 2011; Scott et al., 2013).

External work has reportedly shown the closest correlation to lab based data, indicating that this may also be a useful measure for sporting organisations to include in their AMS (Wallace

et al., 2014). Wallace et al. (2014) found poor reliability of sRPE and TRIMP, where TRIMP (training impulse) was a product of a weighting factor and training duration. However, the participants of this study were classed as recreational athletes, so it is unclear whether these findings would be reproduced in a cohort of elite athletes. Further, despite controlling for recovery status, not all extraneous variables can be, or were controlled for in this study, e.g. non-training stressors. As such, it is unsurprising that a measure which includes subjective reflection, which is known to be influenced by non-training stressors, was found to vary.

The original TRIMP equation to monitor training load (Banister, 1991), has been the subject of revisions (Borresen & Lambert, 2008). TRIMP is an appealing concept as it distils complex training bouts into a single number to represent training load. However, as heart rate, one part of the equation, can be unrepresentative of training load during high intensity interval training or during differing environmental conditions, the utility of the measure is questionable, particularly for non-steady state exercise (Ian Lambert & Borresen, 2010).

A contemporary issue in the monitoring of training load is the use of the acute to chronic workload ratio (Hulin et al., 2014). The acute to chronic workload ratio consists of a measure of acute training load, typically the work completed over a week, relative to the work done over a longer duration (usually four weeks). These concepts are loosely based on the Banister (Banister et al., 1975) model of fitness and fatigue, where acute workload is comparable to the fatigue component and chronic workload to fitness.

While the fitness-fatigue model was conceived to model and individualise athlete training plans (Banister et al., 1975; Fitz-Clarke et al., 1991), the acute to chronic workload ratio was proposed as a measure to predict injury risk. Publications exploring the use of the acute:chronic workload in various sports argued that spikes in acute workload increased injury risk, while higher chronic workloads were protective against injury, i.e. the training-injury paradox (Gabbet, 2016; Hulin et al., 2014, 2016).

The acute to chronic workload therefore provided an appealing approach to athlete monitoring, where injury risk could be objectified and distilled down to a single number. This concept was arguably particularly attractive to sports scientists who have been primarily trained in reductionism and Newtonian cause and effect (Vaughan et al., 2019), allowing them to communicate complex load monitoring to coaches in a clear and straightforward manner. Consequently, following the publication of the initial concept (Hulin et al., 2014), the use of acute to chronic training workload became quickly embedded in applied sport and exercise science practice (Bowen et al., 2019; S. Malone et al., 2017) and was subsequently endorsed in a consensus statement (Bourdon et al., 2017).

More recently, however, the acute to chronic workload model has come under fire for poor evidence base and methodological rigour (Impellizzeri et al., 2019). In particular, it was claimed that the model had been accepted before a sufficient evidence-base of experimental studies had been established to support it (Impellizzeri et al., 2020). Additionally, some of the data in the original model was unpublished, there was no unified definition of injury across researchers, and the model contained different types of load data including: distance travelled, balls bowled and perceived load (Hulin et al., 2014). Finally, some concerns were raised regarding the statistical methods used to present the data, i.e. discretization (Carey et al., 2018), scaling (Lolli et al., 2019b, 2019a) and smoothing of data (Menaspà, 2016; Murray et al., 2017).

Despite these criticisms, the use of the acute to chronic workload ratio appears to continue in elite sport (Maupin et al., 2020). This is perhaps because despite the lack of evidence-base, it remains a tool that can be used to manage training loads and that has face validity. The proposal and critique of a model in research, juxtaposed with the continuing use of it in practice gives an insight into the gaps between research and practice. Therefore, while the continuing use of the acute to chronic workload ratio in applied practice may not necessarily be detrimental, a failure to understand its shortcomings may lead to ambiguity in interpreting meaningful change in data, or poor decision making in applied practice.

2.6 Athlete Monitoring Systems: Perceptions and Decision-Making

As discussed throughout this literature review, there are many different tools at the disposal of practitioners and coaches that can be used to monitor an athletes' response to training, with some metrics more effective or practical than others (Bourdon et al., 2017; Saw et al., 2015c). While a clear consensus on what tools should be used to monitor athletes has yet to be reached, the perceptions end-users hold of their AMS can be a valuable addition to the research in this area. To date, researchers have instead tended to focus on what parameters to measure, rather than how practitioners and coaches perceive the efficacy and value of the monitoring tools they use (Bourdon et al., 2017).

Two recent research studies have examined the perceptions of AMS efficacy in professional football (Akenhead & Nassis, 2016; Weston, 2018) The majority (84%), of football coaches and practitioners reported that training load monitoring data was beneficial for their training practices (Weston, 2018). However, clear discrepancies were apparent between coach and practitioner perceptions, with coaches reporting that load monitoring systems were less beneficial than practitioners. This is perhaps unsurprising given that one focus of practitioner roles is to interpret and use data to help inform coaching decisions (Coutts, 2016). Caution

should, however, be exercised in interpreting the findings from Weston, (2018), as while the majority of practitioners surveyed (65%) reportedly worked with senior or professional development athletes in the United Kingdom, by comparison, only 20% of the coaches did. Therefore, as elite coaches are under-represented in this sample, it is difficult to ascertain whether or not the findings can be generalised to this cohort. In a different study examining practitioners perceptions of their AMS in premiership football, the actual effectiveness of a load monitoring system was rated as lower than the expected effectiveness for injury prevention, and individual and team performance (Akenhead & Nassis, 2016). This highlights again that, while AMS maybe beneficial, they are yet to meet the expectations of those that use them.

The differences noted above between coach and practitioner perceptions of AMS have been supported by additional research which indicates that although athlete monitoring is an area of interest to coaches, it is not top of their sports science needs (Brink et al., 2017). In comparison to coaches, practitioners generally rate AMS data as more useful to their practice (Weston, 2018). While there are studies that seek general perceptions of coaches on sports science (Krkeljas et al., 2017), beyond football there appears to be very little insight into athlete or elite coach perceptions of AMS efficacy. Failure to understand the successes or shortcomings of the athlete monitoring metrics makes it more challenging to carry out relevant and applied sports science research within elite sport.

As summarised above, there is some evidence that coaches find AMS beneficial to their practice (Akenhead & Nassis, 2016). Coaches are typically the main decision makers when it comes to training programmes, assimilating large amounts of subjective and objective information to inform and contextualise their programme planning decisions (Nash et al., 2011). A limited body of research provides some insight into what coaches want from an AMS (Brink et al., 2018; Roos et al., 2013; Starling & Lambert, 2018); however, the subsequent impact or contribution that AMS data makes to coaching decisions is unclear.

As argued elsewhere (Bourdon et al., 2017), AMS should support and help evidence the decisions coaches make, increase communication between the athlete, coach and practitioner (Bourdon et al., 2017), and promote reflection and improve coaching quality (Cooper & Allen, 2018). Pope et al. (2018) argued that objective sports science data assessing the signs and symptoms of overtraining was largely disregarded by elite rowing coaches. Instead, these coaches relied on observation of the athlete, subjective appraisal and intuition to inform their decision-making and programme planning. Similarly, while both elite coaches and practitioners working in professional football rated training data as at least somewhat important in guiding coaching decisions, coaches subsequently rated the data as not important for winning matches

(Weston, 2018). Overall, it appears that coaches find AMS data useful, but the degree to which it influences their decision making has yet to be fully elucidated. Reducing the volume of data presented to coaches, particularly with large datasets, such as Global Positioning System (GPS) data has been suggested as a way to inform effective decision making (Nosek et al., 2020).

2.7 Barriers and Facilitators to Athlete Monitoring System Use

This literature review has so far explored the theory behind why athlete monitoring is important in elite sport, and, what athlete monitoring measures are popularly employed in both applied elite sport and published scientific literature. However, due to the reported poor buy-in and adherence of coaches and athletes to AMS (Barboza et al., 2017; Saw et al., 2015a), it is important to examine the barriers and facilitators to AMS use in order to improve AMS uptake and to help ensure that the aims of optimising performance and reducing illness/injuries are met.

A thematic analysis has identified barriers and facilitators to AMS implementation across a range of elite Australian sports, with athlete/coach buy-in, ease of AMS use and feedback amongst the factors identified (Saw et al., 2015b). However, this article gave no indication of the relative importance of each theme. Given the large number of potential issues reported by Saw et al (2015b) (14 higher and 28 lower order themes), it is unclear which are the key items for SSM and practitioners to tackle; realistically these items need to be prioritised for practicality. With the aim of clarifying this, the most popular themes, denoted as those in the top quartile of the total meaning unit, or cited by the most number of interviewees, were extracted from published data (Saw et al., 2015b). The most popular themes related to the mode of the AMS delivery, feedback of results to athletes, athlete buy-in, individual differences in interpretation of response scales, and AMS reinforcement. Other researchers (e.g. Barboza et al., 2017; Ekegren, Donaldson, et al., 2014), have also highlighted these issues as key areas to target. As these themes appear to be the most discussed barriers and facilitators that relate to athlete engagement, they are consequently discussed in more detail below.

2.7.1 Delivery Mode of Athlete Monitoring System

Since the advent of smartphones, tablets and mobile applications, it is now possible for athletes, coaches and the MDT to have 24/7 access to an AMS, online or offline, wherever they are in the world (Halson, 2014; Roos et al., 2013). The successful use of AMS technology in sport has been demonstrated (Ekegren, Gabbe, et al., 2014); however, the move towards online systems has been swift (Foster et al., 2017), and despite assertions of its successful implementation (Saw et al., 2015b), the evidence supporting the use of technology for AMS is

currently limited. Poor adoption of online surveillance technologies has been reported (Barboza et al., 2017; Ekegren, Donaldson, et al., 2014), and currently it does not appear that any research has contrasted the implementation of an online system with other formats in elite sport. Consequently, caution should be exercised when recommending online systems as a panacea to poor adherence, as current research provides limited insight into whether online systems are the most favourable platform to promote adherence to AMS in elite sport.

In comparison to the lack of studies in elite sport, health research has completed some comparisons of paper and electronic diaries (Stone et al., 2003) and paper, website or mobile applications (Carter et al., 2013; van den Berg et al., 2011). In these examples, technology was found to have improved patient adherence in comparison to paper diaries, with mobile applications outperforming websites. Where paper questionnaires were sent as a follow up to website-based surveys, response rates improved further. In contrast, however, other health research has found that mixed mode (website questionnaire followed by pen and paper follow up), received higher response rates than a postal survey (Zuidgeest et al., 2011). It is therefore reasonable to be cautiously optimistic that technology will confer similar adherence benefits for AMS within elite sport, especially as the relative youth of the elite athlete community mean they will likely be technologically literate, and own smartphones (Gould et al., 2020). However, caution should be exercised, as further research is warranted to evidence the efficacy of the use of technology as a means for collecting AMS information in the elite sport environment.

2.7.2 Are Athletes Responding Truthfully to their Monitoring?

Both athletes and sports personnel have reported concerns regarding athlete responses to AMS, as untruthful or poor reporting practices negate the point of an AMS (Halson, 2014; Saw et al., 2015b). Previously, accounts of athletes being untruthful in their reporting practices, in particular 'faking good,' have been cited as a barrier to AMS implementation (Saw et al., 2015b). Survey fatigue and fear of punishment have been identified as possible reasons for untruthful or indifferent reporting tactics (Burgess, 2017; Saw et al., 2015b). As such, the frequency of AMS administration, questionnaire length, transparency of data use, and ease of AMS use should be considered to minimise poor reporting practices (Bourdon et al., 2017; Gabbet et al., 2017; Manley & Williams, 2019). Solutions to the problems typically encountered when transferring research into practice have however been limited in their scope (Eisenmann, 2017; Saw et al., 2017) or have not directly addressed the reported perception of coaches making unfair decisions on training programmes.

Untruthful reporting practices can be measured, and perhaps more importantly corrected for as demonstrated in health research through inclusion of a social desirability response scale

(SDRS) (Crowne & Marlowe, 1960; Prather et al., 2017; Van de Mortel, 2008). However, it does not appear that these methods have yet been applied to AMS in elite sport.

If utilised, the SDRS requires careful incorporation into a sport's programme to achieve both a successful and scientifically robust approach (Prather et al., 2017). This includes ensuring athletes do not feel alienated by SDRS's use and whether its use is feasible given the time and resource burden of its implementation and subsequent analysis (Saw et al., 2017). Furthermore, sports with small sample sizes and datasets are unlikely to achieve sufficient statistical power to control for social desirability as a confounder, so an alternative would be to use the normative values (Andrews & Meyer, 2003) to highlight atypical reporting patterns. Caution should be exercised, however, as these normative values are not based on a sporting population. Ultimately, building a culture of trust with athletes through agreed, transparent and proportionate responses to their monitoring results may provide the best foundation for a sport to build on, as further assessment of athletes who may already be disenfranchised with the monitoring process may not be a politically or practically astute decision (Kristiansen et al., 2012).

2.7.3 Athlete Monitoring System Adherence Rates

Despite recent guidelines outlining requirements for a successful AMS (Saw et al., 2017), there still appear to be difficulties in maintaining coach engagement and athlete adherence to AMS completion (Barboza et al., 2017). The limited information published on elite athlete adherence to AMS has shown a range of adherence rates, with 79% adherence over a 48-week data collection period reported by Cunniffe et al. (2009). In comparison, Saw et al. (2015a) reported lower AMS adherence rates of 42.5 ± 43.5% in a group of mixed ability athletes, with rates of 56 ± 25% in a group of elite Brazilian athletes (Barboza et al., 2017).

What these headline figures fail to indicate is decline in athlete engagement with AMS over time. Attrition rates are rarely quantified, or addressed within published research, making it difficult to ascertain whether there is a trend in attrition rates over time. However, from published figures, attrition rates can be approximated. Figures show a mean attrition rate of 47 ± 11% over 12 weeks of AMS data collection in elite Brazilian athletes, climbing to 59 ± 10% by week 16 (Barboza et al., 2017; Barboza, personal communication, February 12, 2018) and ~30% over 16 weeks in a group of mixed ability athletes (Saw et al., 2015a). Higher starting adherence rates of approximately 75% were seen in team sport athletes who received support from their coach or other staff members to complete the AMS, with adherence increasing to approximately 88% over the same 16-week period (Saw et al., 2015a). This range of positive

and negative adherence rates over time indicates that good adherence is possible, but the environment and context may be key to the success of the AMS.

While most research has demonstrated a decrease in adherence rates over time, the lowest adherence rates were typically seen between 12 and 16 weeks following implementation of the AMS, after which time rates generally plateaued (Barboza et al., 2017; Saw et al., 2015a). Adherence patterns generally follow an exponentially decreasing pattern, but it does not appear that this particular trend, nor the similarities in the timeframes of the low point have been previously identified in an elite sport context. However, comparable trends in attrition rates have been noted elsewhere in health research (Sperandei et al., 2016). Future research that tracks AMS adherence should include attrition rates over time to determine if this trend persists, assisting sporting organisations to adopt strategies to deal with such concerns.

2.7.2 Theoretical Basis of Athlete Monitoring System Engagement

Buy-in and engagement are key deciding factors in the success of an AMS (Saw et al., 2015b, 2017), particularly as end-user opinions can influence AMS buy-in more than the objective benefits of the AMS alone (Donaldson & Finch, 2012). Given the importance of the role of AMS in mitigating athlete maladaptation and optimising performance (Halson, 2014), it is surprising that few research articles have discussed end-users needs, perceptions and opinions of their AMS.

The limited research in this area has revealed that coaches wish for a feasible and practical AMS, where key information on training load and athlete health is distilled into a simple and intuitive overview of pertinent points that are able to 'learn' from historical data (Roos et al., 2013). Athletes reported similar requirements (Saw et al., 2015a, 2015b), additionally requesting that the AMS have an online and offline mobile platform interface with non-ambiguous, highly relevant questions that require minimal effort to complete. While generally supportive of a clean and simplistic approach to athlete monitoring, practitioners expressed concern around survey fatigue, the potential of athletes misreporting their data, and the need to establish a careful balance between the brevity of the AMS and gaining enough useful and valid information to detect meaningful change in athlete fatigue status (Burgess, 2017; Saw et al., 2015b).

A successful AMS therefore needs to strike a challenging balance. It should satisfy the requirement for sports specificity and expedient data collection, whilst gathering enough pertinent information on athletes' training status to allow simple, fast and effective feedback from the practitioner to the coach and athlete. The limited research findings outlined above have focussed on the practicalities of what needs to change in order to improve end-user

engagement (Saw et al., 2015b). How to remedy these problems, and why sports may encounter engagement issues with coaches, athletes and practitioners requires deeper analysis.

What constitutes 'buy-in' and how it might be achieved has to date been poorly defined in relation to sports science. Within the sphere of organisational change, buy-in has been referred to as a continuum of behavioural and cognitive activities related to an individual's commitment to change (Mathews & Crocker, 2014). Accordingly, an operational definition for buy-in within the context of an AMS for this thesis has been defined as change to an individual's cognitive (attitude and beliefs) and behavioural (actions) commitment to the AMS.

The transtheoretical stages of change model (TTM) provides a theory which can conceptualise the various stages of change an athlete or coach may experience in relation to buy-in (J. O. Prochaska et al., 1970). Although arguably this is the dominant model in this area to reflect where an athlete or coach might be in their stage of change, or in this context in relation to their engagement with their AMS, it has also been subject to criticism (Armitage, 2009; Brug et al., 2005). The main criticisms levelled at the TTM include that the linear nature of this model does not always lend itself well to describing the complexities of movement through the stages of behaviour change, and a lack of clarity pertaining to the time course of each stage (Brug et al., 2005). Revisions of the TTM over the years have addressed some of these issues (J. O. Prochaska & Velicer, 1997), but it remains a controversial model with flaws that have yet to be fully addressed (Armitage, 2009).

Underpinning an athlete or coach's stage of buy-in to an AMS is their motivation to change and progress through the stages of the TTM. Research in psychology has produced different theories of motivation (Standage & Ryan, 2019), however, self-determination theory (Deci & Ryan, 2002), provides a framework for defining intrinsic and extrinsic motivation sources, and a theory for framing motivational studies which has been frequently used and reviewed in sports science research (Standage & Ryan, 2019).

The central constructs of self-determination theory posit that the basic psychosocial needs of relatedness, competence and autonomy determine an individual's motivation. Relatedness has been defined as the need to care or be cared about by others; autonomy the need for people to feel ownership over their behaviour; and competence the need to produce desired outcomes to experience mastery (Deci & Ryan, 2002).

When contextualised to AMS, sporting organisations should therefore consider to what extent their AMS meets these psychological needs. For example, AMS tend to be deployed top-down,

i.e. they are imposed by the sporting organisation on the athlete, and are often mandated, linked to athlete funding, or enforce punitive measures (Saw et al., 2015b). Therefore, it is appropriate to consider how the mandatory imposition of monitoring may impact both the athlete and coach in relation to the psychosocial needs as described in self-determination theory (Deci & Ryan, 2002), e.g. an athlete's perception of autonomy when they have little to no control over the content or frequency with which they are required to complete their monitoring. As reported by researchers (Coyne et al., 2018; Saw et al., 2015b), there is an acknowledgement that buy-in of key stakeholders is an important component of AMS success; however, there appears to be an underlying assumption that it will just be 'achieved,' with little thought given to either how to achieve it, or whether in achieving buy-in there is a negative impact on the consequent psychosocial needs of the athlete/coach. This latter point relates to the underlying philosophy of monitoring athletes which is discussed in more detail in Chapter 8.

2.7.3 Coach Engagement

Inadequate coach engagement with AMS has frequently been reported in the literature by both athletes and other members of the MDT (Burgess, 2017; Saw et al., 2015b). While coach engagement has been highlighted as important to athlete monitoring (Saw et al., 2017), the consequences of non-engagement have not been explicitly outlined in research investigating AMS use. If coaches fail to engage with an AMS the result may lead to disenfranchised athletes, frustrated practitioners (Saw et al., 2015b), potential failure to implement the AMS (Saw et al., 2017), and, ominously, the risk of poor performance through failure to adequately monitor and adjust training to athlete needs (Halson, 2014). Coach engagement with AMS is thus absolutely fundamental to the success of an AMS. As a result, it is important to understand the origins of poor coach engagement and how it might be resolved.

Research to date has mainly attributed poor coach engagement to sport science being inaccessible to coaches as a result of: the scientific language it uses, failures to translate findings into practical applications, or because research is generally inaccessible in pay-walled journals (Buchheit, 2017; Eisenmann, 2017). Other reported issues include metrics such as AMS usurping coaching craft in driving targets, funding, and performance assessment (Buchheit, 2017; *Mission 2016/18 | UK Sport*, n.d.).

Other potential barriers to engagement, such as job role territoriality, internal conflicts and adversity to change have received little research attention, perhaps due to their sensitive nature (Eisenmann, 2017). These concerns regarding coach engagement with AMS are set against a globally variable coach education programme, with a recent survey finding 15% of the Norwegian national team coaches had no formal coaching education (Fasting et al., 2017),

whereas in contrast, the majority of a group of national Canadian national team coaches surveyed had received formal coach education (Werthner & Trudel, 2009). Given the backdrop of inconsistent coach education, coaches predominantly learning their craft from their peers (Rynne & Mallett, 2014; Stoszkowski & Collins, 2016), and the recent exponential drive to embed sport science in coaching (Day, 2011). It is unsurprising that some coaches may lack confidence to interpret or engage with some of the scientific measures within an AMS, or feel strongly that it shouldn't replace their coaching eye and intuition (Buchheit, 2017; Burgess, 2017; Day, 2011; Gabbet et al., 2017; Roos et al., 2013).

Despite the recognised barriers to coach engagement, little has been done to promote coaches' commitment to more formal AMS methodologies, or to support practitioners in attaining this buy-in (Burgess, 2017; Eisenmann, 2017). For example, the flowchart presented by Saw et al. (2017) provides useful guidance on what needs to be done to implement an AMS (Figure 6). However, within the flowchart the box that advises 'develop buy-in' in relation to stakeholders (including coaches), is a difficult milestone to achieve, and no guidance is given on how to realise this goal. Practitioners working alongside elite coaches would therefore benefit from further guidance on how they might realise this goal, be it through (in)formal education (Day, 2011), behaviour change tools (Michie et al., 2011) or other intervention methods.

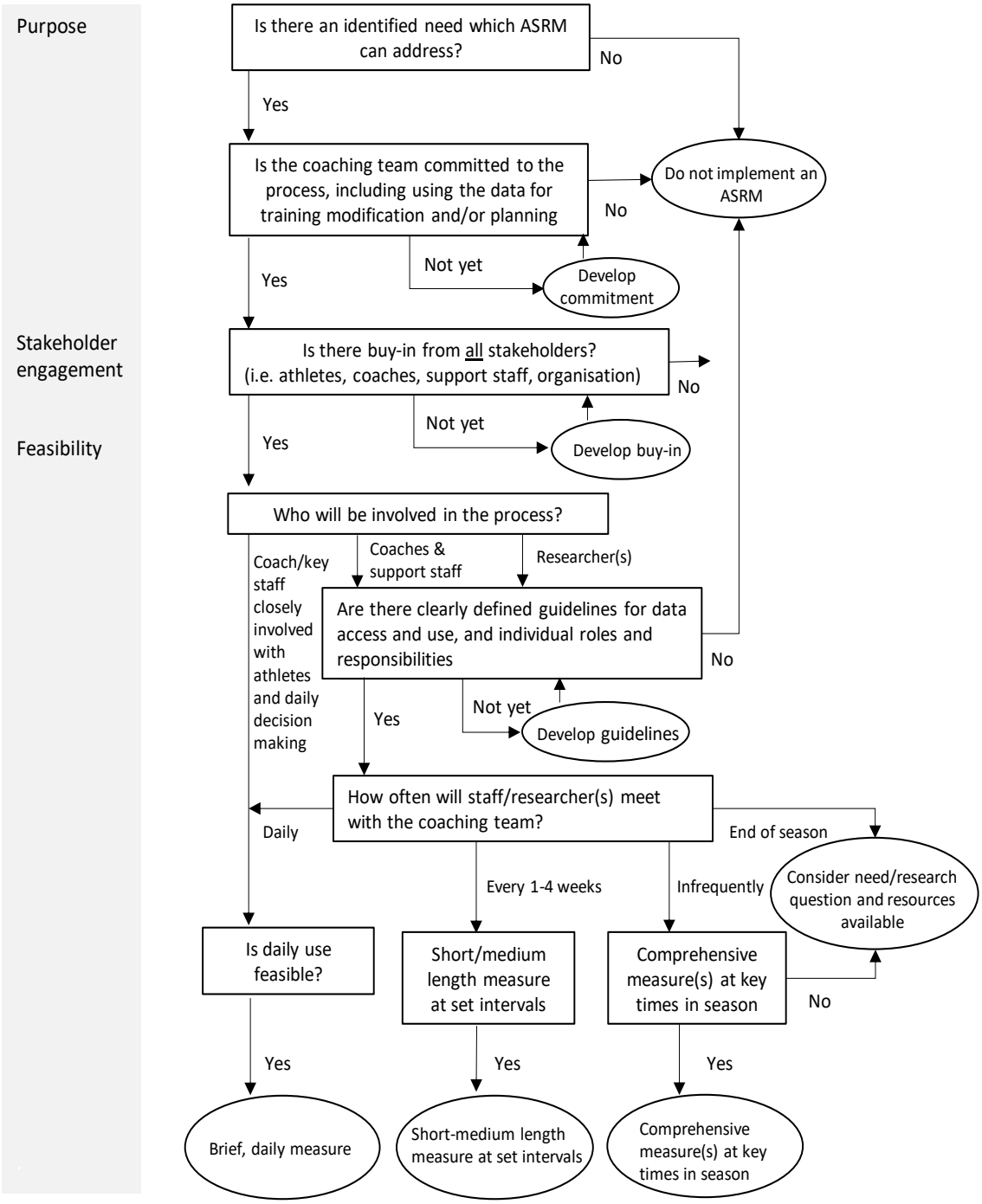

Figure 6. Adaption of the steps to establish the purpose, stakeholder engagement, and feasibility of implementing an athlete self-report measure (ASRM) in a sport context from Saw et al. (2017).

2.7.4 Athlete Engagement with Athlete Monitoring Systems

Athletes are usually the key focus in achieving adherence and engagement with the AMS, along with coaches, their continued buy-in is central to AMS success. Without athletes' self-report data, the scope of any AMS is severely limited (Halson, 2014; Saw et al., 2015b). Widely varying levels of elite athlete adherence have been reported in the literature (Barboza et al.,

2017; Cunniffe et al., 2009). Surprisingly, no published criteria currently exists that quantifies minimum acceptable adherence rates, perhaps as a result of the variable content of AMS between sporting organisations (Taylor et al., 2012). The most compliant athletes have been reported as team sport athletes who are supported by their sporting body/coach (Saw et al., 2015a). In contrast, individual sport athletes who operate remotely from their sport's geographical base, particularly those who have a poor supporting infrastructure or unfavourable relationships with coaching staff, were less likely to adhere to AMS (Jowett & Cockerill, 2003; Saw et al., 2015a).

While this research gives an overview of the contexts that are most conducive to AMS adherence, it does not fully explain the variance reported in AMS adherence within a sport (Barboza et al., 2017). Individual differences, such as athlete autonomy, self-efficacy or motivation, as described by the self-determination theory (Deci & Ryan, 2002), may further influence athlete adherence levels to monitoring (Hodge et al., 2009). Notably, athlete engagement was not discussed in a recent commentary on obstacles to implementing sport science in applied practice (Eisenmann, 2017). Instead, coaches and athletes were referred to as one unit, with an assumption that they would have similar expectations or concerns on science within their sport. This approach fails to consider the differing opinions athletes have from coaches on their AMS, which have been discussed elsewhere (Saw et al., 2015b).

Health promotion research may provide more insight into reasons for varying adherence to AMS. For example, individuals who reported less success with previous behavioural change interventions were likely to have lower engagement with subsequent web-based health promotion interventions (Usher-Smith et al., 2017). Tailoring the intervention based on factors such as prior engagement history and perception of risk to health was proposed to help overcome poor adherence. Given the parallels between implementing an AMS and health promotion research (Usher-Smith et al., 2017), it is tempting to consider whether the solutions posed for promoting engagement, such as improving self-efficacy, may also be effective for improving AMS adherence in an elite sport environment.

2.7.5 Practitioner Engagement with Athlete monitoring Systems

Practitioners are usually the architects and/or administrators of the AMS (Taylor et al., 2012), and subsequently their engagement with the AMS is likely to be less problematic, and as a result this has not been highlighted as a significant concern in research to date. Nonetheless, if the AMS is not well planned, practitioners may experience excessive time pressure to feedback results, and conflicts with coaches may occur if a balance between scientific data collection for the AMS and coaching craft is not achieved (Burgess, 2017; Day, 2011). Practitioners have also

expressed frustration at the ongoing need to 'sell' the AMS to athletes and coaches, with engagement and buy-in a continuing struggle (Saw et al., 2015b). The findings outlined above underlines the importance of ensuring the engagement and buy-in of key personnel into the AMS.

Unsurprisingly, however, the result of poor engagement from athletes or coaches may result in practitioners becoming disenfranchised with the AMS (Saw et al., 2015b), threatening its ongoing effectiveness. As indicated above, strategies to prevent disillusionment, through tackling buy-in from key personnel such as the coaching team should be incorporated into guidance for SSMS and practitioners (Saw et al., 2017).

Key themes known to affect AMS engagement and adherence have been discussed in Chapter 2.7.3 and 2.7.4. In order to provide a foundation for a successful AMS, risk factors which may undermine the success of it should be identified and addressed in the planning phase (Saw et al., 2015b). Engagement with an AMS has been identified as one of the factors that is important to achieve (Saw et al., 2015b) and behaviour change models can provide an evidence-based mechanism for this (Michie et al., 2011).

2.7.6 Using Behaviour Change Techniques to Facilitate Athlete Monitoring

Saw, Kellmann, et al. (2017) provided a flow chart (see adapted version in Figure 6) demonstrating a step-by-step process for implementing an athlete-self-report measure in a sport. While this is not an implementation flowchart for an AMS, the process and steps remain very similar. "Develop Commitment and Buy-In" are two stages included in this flowchart (Figure 6). While these are vitally important steps (Buchheit, 2017; Burgess, 2017), no indication is given by these authors, nor elsewhere in this particular field of research, on how to achieve buy-in and engagement of stakeholders to an AMS. The inter-personal skills of practitioners alone are instead relied upon to gain the traction and engagement required to realise these objectives (Burgess, 2017; Gabbet et al., 2017). As the success of the AMS can be decided by buy-in or commitment of key personnel, being vague about the practicalities of how to go about this, and assuming practitioners could or should achieve this important step alone invites failure (Halson, 2014; Saw et al., 2015b, 2017). This is a significant gap in current research that needs to be addressed.

Health scientists working in allied fields have faced similar obstacles to obtaining buy-in when trying to implement health initiatives. To this end, health initiatives are often underpinned by behaviour change techniques and theories in an effort to increase their chances of success (Hallam & Petosa, 2004; Prestwich et al., 2013). Given the difficulties faced in embedding AMS in elite sport and what appears to be a lack of an evidence-based approach for achieving

athlete and coach engagement (Saw et al., 2017), implementing behaviour change techniques may provide the structure practitioners need to increase the chances of AMS success.

To address some of the issues raised around poor buy-in, some researchers have advocated following a social ecological approach when implementing an AMS (Saw et al., 2015b); this methodology has also been observed in other sporting contexts (Henriksen et al., 2010). Other approaches have promoted the use of Complex Adaptive Systems as a framework for understanding both individual behaviours and wider social processes (Gomersall, 2018). Michie et al. (2011) proposed a framework for implementing behaviour change interventions based on an ecological approach; the Behaviour Change Wheel was proposed as a framework to provide practical guidance on how to administer a behaviour change intervention in an applied setting. The Behaviour Change Wheel is underpinned by both a theoretical model of behaviour change and a fully comprehensive and coherent set of possible behaviour change interventions (Michie et al., 2014). This framework was specifically designed to ensure a more systematic approach to intervention design and review, aiming to avoid the ISLAGIATT (It Seemed Like A Good Idea At The Time) approach which may otherwise be employed (Michie et al., 2014). Since its inception, this framework has been applied widely in health research (F. Barker et al., 2016; Sinnott et al., 2015). In elite sport it has been theorised that the behaviour change wheel could reduce inadvertent doping (Backhouse et al., 2017); however, there does not appear to be evidence of it being applied, administered and evaluated in elite sport in relation to AMS. This may be due to a lack of awareness of this framework, or practitioners not having the time or scope to utilise this approach.

Frameworks such as the behaviour change wheel could be quite time-consuming to plan, given their systematic and comprehensive nature (Michie et al., 2014). This time commitment will need to be offset by the chance of increased success of the AMS intervention (Davis et al., 2015), and balanced against other competing priorities within the sport. Unless new research can demonstrate that application of the behaviour change wheel in elite sport can improve AMS engagement, and outweigh the initial time burden it presents, its utility may continue to be overlooked.

2.7.7 What about the Athlete?

The majority of this literature review has considered what tools should be used to monitor athletes, how they should be deployed and how best to engage coaches and athletes to take part in this process. It is easy to gloss over how persistent, sensitive and sometimes invasive monitoring processes may impact the athlete personally, and in potentially unintended ways. Recent discussions in the literature have raised the issue of monitoring becoming akin to

hostile surveillance cultures seen in the workplace (Manley & Williams, 2019). The point at which an AMS tips from being supportive of athletic performance to having an adverse effect on those being surveilled is unclear. However, some hallmarks of more hostile surveillance environments may include: the surveillance inducing persistent feelings of fear, anxiety and precariousness in athletes, privacy concerns, measurements 'creeping' or becoming insidious, a lack of personal/professional boundaries, poor data transparency with an inability to challenge findings that can impact athletic careers, and athletes consistently resisting or subverting the monitoring process (Ball, 2010; Manley & Williams, 2019).

As this literature review has discussed, within an AMS, athletes and their performances are reduced to numbers. Furthermore, there is a push to reduce and simplify these numbers as far as possible with the implementation of traffic light or red flag rating systems (Gallo et al., 2017; Robertson et al., 2017). Data simplification is driven by the inherently reductionist philosophies of sports scientists (Vaughan et al., 2019) and a need to streamline what are often complex and rich datasets for coaching consumption (Roos et al., 2013; Starling & Lambert, 2018).

The end result are algorithms and datasets that can be perceived to lack transparency or that are inaccessible to athletes, but that nevertheless have the potential to guide significant decisions about their athletic careers (Manley & Williams, 2019). It is therefore no surprise that there has been some emotive discussion around the role of AMS in elite sport (Collins et al., 2015; Shaun Williams & Manley, 2016), but perhaps of more note is that such academic discourse is not more widespread.Arguably, becoming an elite athlete now means surrendering some portion of your personal life to external scrutiny. Monitoring has now crept from the training venue to the athlete's home via mobile applications (*Case study: PDMS*, n.d.) and even while athletes sleep (Leeder et al., 2012), further blurring the boundaries between work and play (Sanderson, 2016).

Technology has fuelled the approach of 'ever-greater monitoring,' (Ryall, 2019). The advent of wearable technology and big data, (where extremely large, complex and heterogeneous datasets are captured in relation to the athlete and their performance) has enabled more and more measurement of athletes (Baerg, 2017; Cave et al., 2020). This change is evidenced by the role of data analysts, who analyse and interpret such big data, becoming an increasing mainstay of sporting organisations (Gerrard, 2017). While accumulating big data can be beneficial for understanding an athlete and their performances (Bourdon et al., 2017), where monitoring technologies are employed with little reflexivity, practitioners risk becoming data-driven, rather than data-informed. The skills of critical thinking and professional judgement

may be overlooked, with practitioners focus becoming centred on the monitoring data alone, a proxy measure for athletic performance itself (Gamble, 2020; Manley & Williams, 2019).

Some sporting organisations have pursued monitoring strategies that are perceived as over-zealous or excessive in nature by the athletes on the receiving end of such practices (Manley & Williams, 2019; Shaun Williams & Manley, 2016). Researchers and applied practitioners should therefore consider the consequences, unintended and otherwise, of top-down athlete monitoring processes and AMS should aim to add to, rather detract from the athlete experience. The potential harms of being driven by rather than informed by the data may further exacerbate any issues with methodological rigour or poor buy-in (Pope et al., 2018; Saw et al., 2015b). Accordingly, ensuring AMS are founded on sound scientific principles and rigour and are supported by both critical thinking and astute professional judgement may help combat some of the issues raised in this literature review (Crowcroft et al., 2020a; Pope et al., 2018). Overall, the impact of surveillance on the athlete and the potential negative implications of sub-optimal operation of AMS in elite sport provides further weight to the rationale of exploring AMS practices in elite sport within this thesis.

2.8 Athlete Monitoring in Elite Sport: Where Next?

This literature review has examined the reasons for athlete monitoring in elite sport, current trends of monitoring training, facilitators and barriers to athlete monitoring engagement, and the typical content of AMS as indicated by the criteria for over-training diagnosis.

Research has highlighted the benefits of athlete monitoring in elite sport (Drew & Finch, 2016; Halson, 2014), with some recent concerns raised regarding unintended consequences a surveillance culture can bring (Manley & Williams, 2019). Nonetheless, very little is known about what AMS measures are employed in elite sport beyond a descriptive account reported for Australian national teams (Taylor et al., 2012) and fragmented information from various published research articles (Crowcroft et al., 2017; Saw et al., 2018). This makes it difficult to assess what monitoring is employed in day-to-day practice, and why elite sports have chosen to use certain monitoring measures that have been published. This information void also causes ambiguity related to current and future research direction. The rationales behind the use of these monitoring tools in elite sport and their relative perceived success from personnel within the sport is also unclear. Without this information it is challenging to provide evidence-based guidance or best practice recommendations for AMS in elite sport. A failure to provide such guidance may negatively impact the quality of any AMS and thus the health and, ultimately, performance of elite athletes. Consequently, Chapters 4 and 5 of this thesis will aim

to address this gap by asking elite sport practitioners about the current monitoring measures they use in their sport and their perception of the success of their AMS.

Poor engagement of athletes and coaches with AMS is problematic and may lead to the AMS failing to meet its stated purpose (Burgess, 2017). Engagement with AMS is a recognised problem (Saw et al., 2017), but instead of current research exploring why end users, particularly athletes, have poor AMS engagement, research has instead focussed on the practicalities of what changes need to be made to the AMS itself to ameliorate adherence (Saw et al., 2015b). This has resulted in the proposal of a broad multi-level and multi-factorial approach to resolve issues surrounding implementation of an AMS (Saw et al., 2015b). As sporting organisations' time and resources are often limited (Buchheit, 2017), a more focussed approach to tackling poor engagement would instead be beneficial. Trying to understand first-hand why athletes or coaches may fail to engage with athlete monitoring, and subsequently utilising targeted and evidence-based methods to change behaviours, sporting organisations may therefore save time and money, along with increasing the chances of AMS success (Michie et al., 2011).

While there are examples of researchers successfully implementing evidence-based behaviour change frameworks in health research (Sinnott et al., 2015), similar work has yet to be completed with reference to AMS in elite sport. As such, Chapter 6 explores athlete perceptions of monitoring with the aim of identifying their reasons for non-adherence, along with suggestions for tackling this issue in elite sports. Chapter 7 aimed to extend this work by addressing the poor engagement issues identified in Chapter 6 and assessing the practicality of implementing behavioural change interventions (Michie et al., 2014) to positively impact the perceptions and adherence to a sport's AMS.

3.0 Chapter Three - Methodology

This methodology examines the research paradigms that underpin this thesis. It provides a structure for an epistemic investigation of why the research methods have been chosen, and the principles that underpin them.

3.1 Philosophical Stance

This thesis investigates athlete monitoring practices and perceptions across a broad range of elite sports (national team level) in the United Kingdom, and then subsequently focusses on specific case studies in a water-based sprint sport and a combat sport. Physiological and psycho-social aspects relating to athlete monitoring in elite sport are explored, alongside the buy-in and engagement of key stakeholders, such as athletes and coaches to athlete monitoring.

The research paradigm of this thesis is primarily based on a pragmatic ontology. Such an approach embraces plurality in methodologies, tailoring the research methods utilised to suit the research questions (Kaushik & Walsh, 2019). This ontology supports the mixed-methods approach employed in this thesis and the use of inductive reasoning, where assumptions and hypotheses are tested and broader generalizations supporting those views can then be made (Okasha, 2002). Pragmatic research paradigms are particularly suited to real-world problem-solving, as they allow the researcher to utilise the method of enquiry best suited to answer the research question. Thus, this allows the researcher to reject the dualist concept of either being exclusively objective or subjective, or positivist/interpretivist in the research paradigm chosen (Kaushik & Walsh, 2019).

Modern western research has pursued a reductionist paradigm, with the pioneering work of Hubel and Wiesel paving the way in this area (Wurtz, 2009). Reductionism states that if one wants to understand a complex system, it is possible to do so by breaking the system down into its component parts. When the sum of the component parts is understood, reductionism states the entire system will be understood. This results from the individual parts increasing in their complexity in a linear manner thus producing a complex system. Further reduction of the component parts should reduce the noise and aid understanding of the entire system (Sapolsky & Balt, 1996). Inherently, it is conceptually and mathematically challenging, if not unfeasible, to consider collecting and interpreting holistic information about an athlete, their performance and their environment. Thus, in this instance, reductionism is a seductive philosophical approach; a complex system becomes digestible, and any variability in the system is usually explained as unwanted noise or measurement error (Sapolsky & Balt, 1996).

This thesis primarily utilises a classical reductive scientific approach. However, it is recognised that reductionism has its limitations and that complex systems, particularly human biological systems have non-linear tendencies, which reductionism fails to describe (Higgins, 2002). Consequently, a complex systems lens and a qualitative analysis is applied, where appropriate, in an effort to embrace a more holistic and ecological method of inquiry (Lorenz, 1963).

3.2 **Methodology: Research Design Rationale**

Opportunities to undertake research, such as intervention or case-controlled studies are limited in the elite sport setting. This is due to the constraints of the elite sport system, such as the low number of elite athletes, and the inherently sensitive time frames in a busy competition calendar. Researchers have explored in more detail some of these barriers to implementing research in elite sport (Buchheit, 2017; Coutts, 2017; Fullagar et al., 2019). The use of control groups is generally not feasible in elite sport due to political, ethical or logistical issues in dividing a small training group into two. Typically, the use of a general population control group would also be meaningless (Gathercole et al., 2015). As a result, this thesis has taken a primarily observational approach to gathering data on athlete monitoring practices and perceptions, with a final study examining the implementation of a behaviour change intervention.

The first two studies (Chapters 4 and 5) employed an electronic survey to collect data. This was considered the most appropriate, robust and feasible method to collect data in a from people working in sporting organisations dispersed around the United Kingdom. Such an approach was also perceived as more palatable to the gatekeepers at the English Institute of Sport, as the time commitment and amount of interference with normal working practices a survey involved was less than alternative methods, such as interviews. This approach is supported by other researchers who have demonstrated successful use of surveys to collect data on athlete monitoring practices (Akenhead & Nassis, 2016; McLaren et al., 2019; Taylor et al., 2012). The survey reported in Chapters 4 and 5 had an intentional focus on athlete self-report measures. As reported in the literature (Taylor et al., 2012), this is thought to be one of the most prevalent measures employed in AMS in elite sport. A focus on athlete self-report measures therefore allows cross-sport comparisons that may not otherwise be possible with objective measures, due to the disparate nature of the sports surveyed. Accordingly, a focus on athlete self-report measures permitted reflection on athlete monitoring practices between sports that would otherwise be unfeasible or impractical.

Data in Chapters 6 and 7 were collected through a series of semi-structured interviews. This was supported by questionnaires and athlete adherence data retrieved from the respective

AMS. As Chapters 4 and 5 underlined specific concerns regarding athlete buy-in and engagement with the AMS, there was a clear need to explore this issue in more detail. Semi-structured interviews were deemed to be the most appropriate method of data collection to explore poor athlete engagement, as they create a platform for participants to have an open discussion, whilst also allowing a detailed picture to be built up about their experiences (Silverman, 2010). Semi-structured interviews were favoured above focus groups to allow all participants to present their opinions without any peer pressure. This therefore allowed a more representative picture of the perceptions of all athlete monitoring users (Almeida et al., 2017).

Chapters 6 and 7 utilised a case study approach to data collection. The rationale for this approach was a mixture of practicality and the type of approach required to answer the research questions. As already outlined, working with those inside sporting organisation entails significant issues in relation to access and subsequent permission for publication of data (Coutts, 2016). The author of this thesis had established professional relationships with members of the respective sporting organisations in Chapters 6 and 7. This social capital alleviated access issues, and engendered trust to pursue the different research questions posed. Further, as the research in Chapters 6 and 7 was focussed on gaps that had been identified in the literature, a case study approach allowed a deep and rich exploration of these issues in the context of the respective sporting organisations (Zainal, 2007).

While case studies may limit the generalisability or transferability of the findings, it would have been impractical to pursue semi-structured interviews across multiple sporting organisations. A lack of existing relationships with those inside other sporting organisations would have made this approach particularly lengthy and challenging. The participants in Chapters 6 and 7 were involved with different sports (sprint water-sport versus combat sport). The use of a different sporting organisations is however believed to strengthen the findings presented in this thesis. This is because similar issues, such as poor athlete AMS adherence, were subsequently reported across a heterogeneous cohort of participants. Arguably, it would have been a more consistent approach to work with the same sporting organisation across Chapters 6 and 7. However, this was not feasible due to the water-based sprint sport going through a transition period where they moved their training hub location, and due to political pressures applied at the time (Roan, 2018).

3.3 Procedures and Ethics

The studies contained within this thesis complied with the Declaration of Helsinki (*World Medical Association*, 2013), and all protocols were given ethical approval by the local ethics

board at the Department for Sport, Exercise and Health, at the University of Winchester. Ethical approval was obtained prior to commencing any research.

3.3.1 Participants

Following the receipt of institutional ethical approval participants were recruited via a mixture of convenience and stratified sampling, with, where relevant, written agreement from gatekeepers at the English Institute of Sport. Survey participants in Chapters 4 and 5 were primarily accessed through discipline leads at the English Institute of Sport. This ensured that the survey link reached all practitioners within the relevant sports science discipline. Participants in Chapters 6 and 7 were recruited via convenience sampling. This ensured all female national team athletes from the water-sport to be recruited in Chapter 6, and all coaches and athletes in the combat sport in Chapter 7.

3.3.2 Informed Consent

All participants read a participant information sheet prior to completing written informed consent agreeing to participate in the research. For Chapters 6 and 7, where the first author was present, a full verbal briefing was provided, which reiterated the purpose, methods and any risks associated with participating in the study and assured participants of the confidentiality of their data and anonymity. For Chapters 4 and 5, which were completed online, this information was instead written and included in the survey pre-amble and participant information sheet. These participants were given the opportunity to choose to decline to participate at the outset of the study by clicking on the 'do not agree' box which automatically directed them to the final exit page of the survey. They were also instructed in writing that they could choose to exit the survey at any time. All participants were informed in writing that they could choose to withdraw from the study at any point without disadvantage, or without giving any reason.

3.3.4 Inclusion Criteria

The sampling criteria specified that participants were either practitioners (those practicing sport science/medicine) coaches or athletes affiliated with or working in elite national team Olympic and Paralympic sports. These inclusion criteria were satisfied by working with gatekeepers at both UK Sport and the English Institute of Sport to ensure access to appropriate potential participants. This specific cohort were required in order to respond to the research questions outlined in Chapter 1.2.

3.3.5 Survey

The survey in Chapters 4 and 5 was designed and written by the author of this thesis. It was however informed by discussions from the combined knowledge and expertise of the PhD

supervisory team, alongside information from an existing survey in the literature (Taylor et al., 2012). Where used, Likert scales in the survey had response anchors and conformed with evidence-based research approaches (Lozano et al., 2008; Vagias, 2006). The survey was reviewed for content validity (Stoszkowski & Collins, 2016), and acceptability to the sporting organisations involved, by three applied sports scientists who worked at the English Institute of Sport, and one University sports science academic. The survey comprised of questions relating to: (1) monitoring purpose and background information, (2) data collection, (3) data analysis, (4) feedback of information, and (5) open ended questions on participant opinions of athlete monitoring. Closed questions used Likert-type response scales as presented elsewhere (Vagias, 2006). Free text responses to the survey were grouped into key recurring themes and presented in the text with representative quotations to help further develop the narrative.

3.3.6 Interviews and Interview Guides

Interview guides were used to direct the semi-structured interviews described in Chapters 6 and 7. They were designed to elucidate athlete and coach opinions of their current AMS and to evoke a conversation pertaining to the wider environment surrounding the AMS. In Chapter 6, semi-structured interviews were preceded by a questionnaire with Likert response scales which aimed to inform and promote further discussion in the interviews (see Chapter 12 for interview guide and questionnaire).

3.3.7 Workshop

The workshop described in Chapter 7 was conducted as a group with the author of this thesis and the coaches and coaching management involved in the study. The workshop had several aims, the first was to identify and agree the behaviour change problem the coaches sought to resolve. Secondly, the workshop aimed to outline behaviour change strategies that met with the procedural recommendations for the Behaviour Change Wheel (Michie et al., 2014), i.e. strategies that could bring about positive change within their sporting organisation. The various steps of the behaviour change wheel were followed with the resultant data presented in Chapter 7. A 6-month intervention period was chosen and agreed with the coaching team and coaching management. Practically this worked well as it preceded the main competitive season of the athletes, gave the coaching team time to implement the strategies discussed and allowed analysis of adherence rates over the medium term. In addition, a 6-month intervention period has been demonstrated to allow enough time for behaviour change to occur (J. J. Prochaska & Prochaska, 2011).

3.4 Data Analysis

3.4.1 Survey Data

As the survey data primarily consisted of closed questions, responses were typically presented as percentages, frequencies, or means and standard deviations of the resultant data, calculated using Microsoft Excel 2013® (Washington, USA).

3.4.2 Adherence rates to Athlete Monitoring

All athletes were expected by their respective sporting organisations, to complete their online athlete monitoring daily. Completion rates by athlete were available from the online mobile applications and were downloaded to Microsoft Excel® for analysis for the duration of time outlined in the relevant chapters. Adherence data were then subsequently presented using either group daily percentage adherence rates or mean and standard deviation of adherence for all participants.

3.4.3 Thematic Analysis

Thematic analysis involved a two-stage process. In stage one, an inductive approach was used and, meaningful units of text were attributed to themes and subsequently coded to nodes. This was completed using a six-step approach described in the literature (Braun & Clarke, 2006). This process allowed insight into the experiences and opinions of the interviewees, and the issues they described. The themes were reviewed multiple times and the nodes evolved to ensure the interview results were accurately reflected. The nodes were subsequently grouped into lower and higher order themes. Participants were then sent their transcribed interviews and coded themes and any comments raised were then considered in the construction of the final thematic analysis. In stage two of the analysis, the narrative was developed further by the selection of compelling quotes that represented the respective themes (Anderson, 2010). Processes such as member checking, and the use of themes and meaning units with illustrative quotes, were used to help establish trustworthiness of the findings. Thematic analysis results include the number of participants that had comments coded to a specific theme i.e. meaning units. The frequency with which comments were categorised to a specific theme were collated and presented as the, 'total number of meaning units' in line with accepted practice in qualitative data analysis (Silverman, 2010).

3.4.5 Statistics

Statistical analyses were conducted using SPSS (V26, Armonk, NY: IBM Corp). For the survey in Chapters 4 and 5, Cronbach's alpha was computed to establish the reliability of the survey questions and further establish the trustworthiness of the data. As the data from the survey

did not meet parametric assumptions and were not independent, a non-parametric test of association (Spearman's Rho) was used to assess the statistical significance of the data.

In Chapter 5, data were correlated using Spearman's Rho. For the statistical analysis, α was set at 0.05 and β at 0.80 and a power calculation was conducted to determine sample size using G*Power (V3.1.9.6, University of Kiel, Germany). This is in line with accepted type 1 and type 2 error rates discussed in the literature (Abt et al., 2020).

4.0 Chapter Four - Athlete Monitoring Practices in Elite Sport in the United Kingdom

4.1 Introduction

A survey of practitioners in elite Australasian sport found that 91% utilised an athlete monitoring system (AMS), with injury prevention (Abbott et al., 2018; Taylor et al., 2012) and performance optimisation (Burgess, 2017) being amongst its most important stated purposes. AMS plays an important role in elite sport, as lost training days through illness or injury are a significant issue. At any given time, 36% of elite athletes have a health problem, 15% reporting substantial health problems weekly that may negatively impact sporting performance (Clarsen et al., 2014). For the purposes of this study, AMS are defined as tools or systems within which observations and recordings of key athlete performance parameters are collated.

The use and implementation of AMS have therefore received significant research attention (Burgess, 2017; Gabbet et al., 2017; Saw et al., 2017). However, the current cross-sport trends in monitoring, recording and analysing elite athletic training and performance either go unreported or, at best, fragmented information can be found distributed across research articles (Crowcroft et al., 2017; Saw et al., 2018). This makes it difficult to assess what monitoring is employed in day-to-day practice, and why certain monitoring methodologies have been chosen. Without a clear understanding of what current monitoring practices across sports are, it is challenging to provide evidence-based guidance or best practice recommendations for AMS in elite sport

A survey exploring fatigue monitoring trends in elite sport in Australasia has presented the only mass cross-sport insight into AMS trends to date (Taylor et al., 2012), with no similar data available for the United Kingdom. Athlete monitoring systems from Taylor et al. (2012) were reported to include a variety of performance, laboratory or field tests and athlete self-report measures specific to the sport. Of 55 respondents, custom athlete self-report measures were employed by 84% and collected daily by 55% of respondents. Custom athlete measures are typically created by practitioners within a sporting organisation. They are however stereotypically not subject to the same rigorous process of checking validity and reliability as seen with published measures (Saw et al., 2017). Fitness measures were recorded by 61% of participants, and collected weekly or monthly by 63% of respondents (Taylor et al., 2012). In contrast, validated athlete self-report measures i.e. scales and measures that have been scientifically validated such as the Acute Recovery Stress Scale or REST-Q (Kellmann & Kallus, 2016; Kölling et al., 2020), and hormonal/immune measures were demonstrated to be the most frequently reported in published research for elite and sub-elite cohorts (Drew & Finch, 2016; Lewis, Collins, et al., 2015; Purvis et al., 2010; Saw et al., 2015c). The lack of similar data

on athlete monitoring practices in elite sport in the United Kingdom makes it unclear whether the adoption of custom metrics follows the same pattern as was observed in Australasian sport.

Athlete self-report measures are one of the few measures that are frequently employed across a range of elite sports (Taylor et al., 2012). This is perhaps as a result of the ease of questionnaire administration, customisation and their sensitivity to changes in athlete health (Saw et al., 2015c). The use of custom rather than validated athlete self-report measures questionnaires in elite sport has caused concern (Saw et al., 2017; Taylor et al., 2012); however, researchers have argued that custom athlete self-report measures may still be sensitive to changes in athlete health (Burgess, 2017). The response scales used in athlete self-report measures reportedly vary, with 1–5 (Crowcroft et al., 2017), 1–10 point Likert scales (Montgomery & Hopkins, 2013), and visual analogue scales employed (Gastin et al., 2013). The customisation of athlete self-report measures has also led to variance in how self-report questions are constructed and posed to athletes (Crowcroft et al., 2017; Gallo et al., 2017; Gastin et al., 2013), with no reported consensus on best practice.

The most popular athlete self-report measures to explore have included muscle soreness, sleep, and perceptions of wellbeing (Gastin et al., 2013; Taylor et al., 2012). Most of these variables have been reported as responsive to changes in athlete health or fatigue status; however, sleep quality has been found to be unresponsive (Saw et al., 2015c). Limited relations have been reported between sleep efficiency, sleep duration and injury (Dennis et al., 2016).

AMS data are primarily collected through the use of mobile devices (Crowcroft et al., 2017; Gallo et al., 2017; Gastin et al., 2013). While technology can simplify the process of data entry, collection and review, it remains to be seen if online data collection positively impacts adherence and engagement with AMS. Poor adherence to AMS via mobile devices has been reported where limited or no support from practitioners is available to athletes (Barboza et al., 2017; Saw et al., 2015a). Poor adherence is further exacerbated when technological issues inhibit or complicate data entry (Saw et al., 2015b). Consequently, the use of mobile devices might be better viewed as a tool to trigger wider conversations between the athlete and sports personnel (Saw et al., 2017), rather than as a panacea for AMS adherence problems.

Within athlete monitoring datasets, separating the signal from the noise, discerning meaningful change, and interpreting practical significance has led to a move away from assessing statistical significance, and towards methods such as identifying the smallest worthwhile change (Hopkins, 2004). Further, while there has been recent criticism of data

analysis tools such as acute to chronic workload ratio (Impellizzeri et al., 2020), there has also been discussion of best practice methodologies for AMS datasets (Saw et al., 2017; Thorpe et al., 2017), with recommendations for data analysis at the individual (Atkinson et al., 2019; Hecksteden et al., 2015) and group level published (H. R. Thornton et al., 2019). Some studies point towards some of these methods being employed in elite sport (Akenhead & Nassis, 2016; Crowcroft et al., 2017; Gallo et al., 2017), but it is unclear if this shift towards contemporary statistics use in applied practice is a result of discrete research projects meant for publication, or if the data analysis changes are embedded in the day-to-day practice of practitioners. This lack of clarity is exacerbated by little current insight into data analysis practices for AMS in elite sport in the United Kingdom.

Feedback on the analysed AMS data to athletes has been highlighted as important to maintaining athlete engagement with AMS (Barboza et al., 2017), and a step towards developing a supportive AMS culture (Saw et al., 2017). Current AMS feedback practices within elite sport are under-reported, with descriptions of feedback 'generally' occurring daily (Taylor et al., 2012), or sometimes not at all (Barboza et al., 2017). Further clarification of practitioners' approaches to feedback within elite sport are required, which would enable future research to propose evidence-based feedback practices to promote athlete AMS engagement.

Overall, there is a lack of clarity on what athlete monitoring occurs in elite sport in the United Kingdom, from initial data collection through to data analysis and feedback. This is problematic, as it is unclear whether some of the issues outlined above, such as unclear validity of custom metrics and poor athlete adherence therefore risk negatively impacting the ability of elite sporting organisations to prevent athlete maladaptation (Halson, 2014). As the use of athlete monitoring and athlete self-report measures are endemic in elite sport, this study aims to give an overview of the athlete monitoring methodologies employed by practitioners working at the coalface of elite sport, and to highlight any areas of best practice or concern.

4.2 Methods

4.2.1 Participants

Seventy-five elite sport practitioners (i.e. sport scientists, such as physiologists working with national team athletes) were invited to participate in a secure online survey (Online Surveys, JISC, Bristol, UK) about athlete training and monitoring practices in their sport. Participants received emails inviting them to participate via gatekeepers (their discipline leads) at the English Institute of Sport. Following the initial invite, two email reminders were sent at two

and approximately four weeks after the initial invite. The return rate to the survey was 40%. Respondents were selected through a mixture of stratified and convenience sampling. Sports science discipline leads within the English Institute of Sport emailed the survey to all staff, and further convenience sampling occurred where known staff members who worked within Olympic or Paralympic sport, but who were not affiliated with the English Institute of Sport were followed up separately. Access and written agreements were gained through gatekeepers at the English Institute of Sport or the relevant sporting organisations. Direct quotes are included from free-text responses, whilst participants are identified using codes e.g. P1.

Ethical approval was granted by the University of Winchester Ethics Committee. All respondents received electronic information and a full written explanation of the study and were subsequently given the opportunity to give electronic written informed consent to participate after they had viewed the study information.

4.2.2 Procedure and Statistics

A password protected link to the survey was electronically sent to the identified practitioners. Any respondents that indicated they did not consent to take part were taken to a separate webpage where no further questions were asked. Respondents that indicated that they did not have an AMS in place were directed towards the end of the survey, and those that did have an AMS were asked to complete the full survey (Chapter 12).

The survey was reviewed for content validity (Stoszkowski & Collins, 2016); by three applied sports science practitioners and a University sports science academic, and informed by previous research in this area (Taylor et al., 2012). This process resulted in several modifications, with one question removed, two added and several questions altered to enhance their readability. The survey comprised of questions under the broad headings of: (1) monitoring purpose and background information, (2) data collection, (3) data analysis, (4) feedback of information, and (5) open ended questions on their opinions of monitoring in their sport. Closed questions used Likert-type response scales, as described elsewhere (Vagias, 2006). A full list of the questions can be found in the Chapter 12.

4.3 Results

4.3.1 Monitoring Purpose and Background Information

Thirty sport science and sports medicine practitioners completed the survey. Direct quotes are labelled with anonymised participant numbers, e.g. P1. Fourteen sports were represented: Athletics, Para Athletics, Boxing, Canoeing (sprint and slalom), Para Canoeing, Cycling and Para Cycling, Gymnastics, Hockey, Judo, Rowing, Rugby 7's, Sailing, Swimming, Taekwondo and

Triathlon. Respondents had 8 ± 5 years (mean ± SD) experience of working in elite sport, and collectively worked with 599 senior national team athletes. Each respondent worked with a different squad within their designated sporting organisation.

AMS were employed by 83% respondents; of which 67% felt that there was a clear AMS implementation strategy, underpinned by a scientific theory that supported AMS implementation. All respondents without an AMS in place indicated a willingness to implement one, but varying reasons prevented this occurring:

> I believe we would benefit [from an AMS]. I feel athlete compliance is the issue. (P3)

> Remote support to a high volume of athletes [prevents monitoring]. However, we have plans to monitor in the future. (P15)

While 84% of respondents indicated that there was a clear aim for collecting their athlete monitoring data, 12% reported that there was an insufficient rationale, with 4% unsure:

> What are we trying to get out of the data? (P2)

> We have some mixed messages coming from managers/coaches/support staff. (P23)

For those that felt they had sufficient rationale for their AMS in place, the most common reasons given for collecting athlete monitoring data were to reduce illness and injuries (33%) and to maintain or optimise performance (38%).

4.3.2 Data Collection

When asked who collected athlete monitoring data within their sport, respondents indicated multiple members of their team shared this responsibility, with 96% of respondents indicating that athletes collected their own data. Other team members reported to collect data included: the medical team (56%), physiologists (48%), coaches (48%), strength and conditioning coaches (40%), performance analysts (16%), nutritionists (12%) and psychologists (4%). The Performance Data Management System designed by the English Institute of Sport (*Case study: PDMS*, n.d.), was used by 50% of respondents, with a further 39% using custom designed tools for data collection. The remaining 11% of respondents used Training Peaks® or Microsoft Excel®. No respondents indicated that they used a validated monitoring tool described in the literature, such as REST-Q or the Acute Recovery and Stress Scale (Kellmann & Kallus, 2016; Kölling et al., 2020).

The most popular mode of collecting self-report AMS data was through mobile devices, with 72% of respondents using this method; 16% used pen and paper; 8% entered data directly into a computer; and 4% collected data verbally. Most sports collected AMS data daily (76%), with

4% collecting it weekly, and 20% employing a varied data collection schedule, dependent upon training phase.

Table 2. Data types collected by practitioners in elite sport using an AMS

Data Type	Practitioners collecting this data (%)
Athlete self-report measures	96
Performance tests	84
Gym loading data	80
Performance tracking during normal training	64
Cardiovascular parameters	60
Blood profiling	32
Other (e.g. DEXA, bodyweight, training load)	12
Hormonal profiling	8

Respondents indicated that they collected a variety of measures: 96% collected athlete self-report measures (Table 2), with performance tests, the second most frequently collected measure, gathered by 84% of respondents. Athlete self-report dimensions with the most widespread use included: sleep, muscular soreness, energy, and illness/injury reporting (Figure 7). Likert scales were the primary method used to self-report wellness (84% of respondents), using a 5 (38%), 7 (5%), or 10 (57%) point scale. Other response scales were used by 12% of respondents, which included percentages and a 'bespoke' scale, with 4% of respondents unsure of what method was used. Just over half (57%) of respondents were unsure why their response scale length had been selected, with one respondent reporting: "5 seems too little [points on the Likert scale], 10 gives a good range" (P2). The remainder of respondents indicated that their response scales were either dictated by the software used, or that they felt the scale gave them sufficient variance and measure sensitivity. Just over half of respondents (56%) incorporated a time period into their athlete self-report measures when asking athletes to reflect on their wellness.

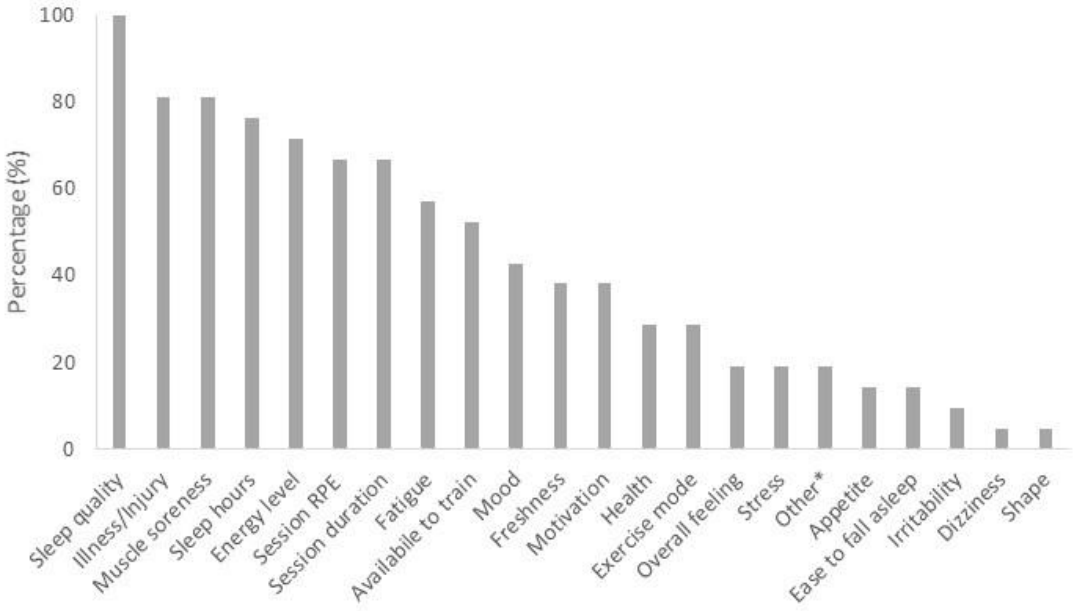

Figure 7. Percentage of respondents collecting various types of athlete self-report measures. *Other includes: fuelling, quality of training yesterday, waking heart rate.

4.3.3 Data Analysis/Feedback

A standardised approach to athlete monitoring data analysis was applied by 76% of respondents. Where no typical analysis method was used, respondents indicated that the "data is [used] as a conversation starter with coaches" (P2), or that "[data is] generally assessed by coach visual inspection" (P9). Where standard analysis approaches were in place, data was primarily analysed by the use of change and raw scores (56%), rolling averages (28%) and percentages (16%). One respondent indicated that their analysis method differed; "depending on coach preferences of feedback methods" (P26).

Meaningful changes within the datasets were analysed through use of standard deviations (20%), raw scores (16%), acute to chronic training load ratios (4%), and smallest worthwhile change (12%). Some respondents reported that they had no defined method to assess meaningful change (24%) or that they were unsure of what method was used (24%).

Overall, 44% of respondents felt that there was insufficient feedback given to athletes, with 20% undecided and 36% feeling that sufficient feedback was given. Formal or informal processes to feedback AMS information to athletes were in place for 84% of respondents. Of the 16% with no feedback process in place, all disagreed with the statement that their athletes received sufficient feedback. In comparison, where feedback processes were in place, 33% felt that athletes did not receive enough feedback on their AMS data. Feedback to athletes was primarily provided face-to-face (57%) and by email reports (24%), with the integral feedback

dashboard from the Performance Data Management System used by 9% of respondents, and the remaining 9% using presentations or bespoke written feedback forms.

The majority (92%) of respondents had daily or weekly discussions of AMS data with the multi-disciplinary team (MDT). In comparison, 68% of respondents had daily/weekly discussions with athletes and 64% with coaches. Athlete monitoring data was reportedly never discussed with the athletes and coaches by 4% and 8% of respondents, respectively (Table 3).

Table 3. Frequency with which survey respondents discussed AMS data with the multi-disciplinary team (MDT), athlete and coach

Frequency of respondents' discussions with:	MDT (%)	Athlete (%)	Coach (%)
Daily	44	28	28
Weekly	48	40	36
Fortnightly	4	16	12
Monthly	4	12	12
Biannually	0	0	4
Never	0	4	8

4.4 Discussion

Insights gleaned from published data in elite sports have to date only provided 'snapshots', or given a limited understanding, of daily AMS practices in elite sports (Gallo et al., 2017; Saw et al., 2018). This study gives a comprehensive overview of practices in athlete monitoring data collection, analysis and feedback in elite sport in the UK, highlighting current trends and areas that require further consideration.

No AMS was employed by 17% of respondents from this survey. This is higher than 9% reported by personnel working in elite Australasian sport (Taylor et al., 2012). While the methodology utilised in this survey aimed to mitigate the impact of non-response bias, it is a reasonable assumption that some still occurred. Therefore, the number of practitioners working in elite sport without an AMS as defined in this survey may be slightly higher than reported. All respondents without an AMS expressed a desire to implement one, but, consistent with previous findings, they reported that poor athlete engagement or logistics prevented it (Saw et al., 2015b). Nonetheless, the vast majority (83%) of sports did have an AMS in place, but, as reported by 33% of respondents, a lack of an evidence-based approach to AMS implementation was apparent.

Respondents gave broadly equal weighting to the AMS aims of preventing injury/illness and optimising performance, consistent with previously reported data (Taylor et al., 2012). A lack of a clear rationale for the AMS was described by 12% of respondents; to the authors' knowledge, the extent of this problem has not been previously reported. Concerns regarding the ability of AMS to effectively deliver injury/illness prediction, prevention and performance optimisation have been recently discussed (Coyne et al., 2018; Sands et al., 2017), and perhaps these concerns mirror the lack of clear AMS aims indicated by some users in this study. Sporting organisations should therefore consider their need and subsequent aims for an AMS in relation to criteria which have been outlined in other spheres of research. Examples include completing a needs analysis to assess the requirements for an AMS (Gürel & Tat, 2017), and assessing AMS aims against SMART objectives (Specific, Measurable, Achievable, Relevant, Time bound) (Bjerke & Renger, 2017). These tools provide a structured framework for a critical analysis of the need and aims of an AMS, that can be subsequently communicated within the sporting organisation as deemed appropriate (Bjerke & Renger, 2017; Michie et al., 2014).

Illness and injury monitoring was one of the key rationales for AMS use reported by 33% of respondents (Figure 7). Nonetheless, 20% of respondents overall did not require athletes to self-report illness/injury status. This is despite illness/injury prevention being one of the key rationales reported in the literature for AMS use (Halson, 2014). The collection of athlete self-report data on illness/injury status is likely more susceptible to misreport or misdiagnosis, in comparison to the analysis of trained medical practitioners. However, an AMS can provide a valuable avenue for athletes to communicate any perceived health issues, which can then be flagged to the coach or multi-disciplinary team as appropriate; therefore the inclusion of such parameters is arguably warranted (Roos et al., 2013; Starling & Lambert, 2018). Furthermore, while a range of personnel collected AMS data, 44% of respondents did not specify that athlete monitoring data was collected by their medical team. These findings contradict previous research that has demonstrated a close relationship between the medical team and elite athletes, with periodic health reviews and illness/injury monitoring being standard practice (Dijkstra et al., 2014). These apparent differences could be due to misinterpretation of the survey questions, but, more likely, it is a result of medical information being kept separately from day-to-day athlete monitoring data, for confidentiality purposes. This separation of datasets, while often necessary from a privacy perspective, risks causing a silo'd approach to both data management and thinking that, left unaddressed, could prevent a holistic understanding of athlete health and training status (Dijkstra et al., 2014).

Data collection for AMS was primarily completed via mobile devices, with 72% of respondents using this methodology. This is consistent with the move to technology discussed in Chapter

2.7.1. However, the efficacy of mobile devices to collect AMS data in comparison to methods such as pen and paper remains unclear. In health literature, some research has shown that mobile platforms improve patient adherence rates in reporting their chronic pain, in comparison to pen and paper (Stone et al., 2003), whilst others have shown a mix of questionnaire delivery modes to be more effective (Zuidgeest et al., 2011). No similar analyses of data collection methods appear to have been conducted in elite sport however, and while technology can aid data collection and analysis, it is unclear whether this technological shift has improved engagement with AMS, especially in light of poor reported athlete adherence (Barboza et al., 2017). Monitoring data should trigger wider conversations between athletes and sports personnel (Barboza et al., 2017; Bourdon et al., 2017); if instead the use of online monitoring technology is perceived as a barrier to discussion, hostile surveillance, or increasing the amount of effort involved to report concerns (Manley & Williams, 2019), the role of technology in relation to athlete monitoring should be re-assessed to promote better engagement with key stakeholders.

The custom-built Performance Data Management System developed by the English Institute of Sport was the most popular method by which to collect AMS information (*Case study: PDMS*, n.d.). This is likely a result of the majority of participants being affiliated with the English Institute of Sport, and the custom Performance Data Management System being available and customisable to them. Similar to previous research (Taylor et al., 2012), there was limited use of other data collection tools, with no respondents indicating that they employed validated athlete self-report measures tools such as Rest-Q (Kellmann & Kallus, 2016) or the Acute Recovery Stress Scale (Kölling et al., 2020), underlining the gap between research and practice.

Researchers have suggested that some custom athlete self-report measures are sensitive to changes in training load (Burgess, 2017). However, the questions and response scales differed across the studies cited by Burgess (2017), and the sports reviewed only included swimming and Australian rules football. Therefore, it is unclear if custom athlete self-report measures would be sensitive beyond these specific contexts. Given the lack of clarity surrounding custom athlete self-report measures it is recommended that practitioners undertake their own validation exercises. However, in lieu of practitioners undertaking time-consuming research to assess the validity of custom athlete self-report measures, practical and arguably swifter alternatives for assessing validity have been proposed (Kyprianou et al., 2019; Windt et al., 2018) but have yet to be reviewed within the literature. In relation to the findings from this study, the evidence-base underpinning the widespread use of custom measures remains unclear and requires further investigation, a point explored in more detail in Chapter 5.

Similar to findings reported elsewhere (Gastin et al., 2013; Taylor et al., 2012), the most commonly employed athlete self-report measures were: sleep quality, muscle soreness and illness/injury status (Figure 7). Subsequent research has however demonstrated poor responsiveness of sleep quality to changes in athlete training status (Saw et al., 2015c). The inconsistency between the widespread use of sleep quality as an athlete self-report measure in elite sport, and its reported lack of sensitivity in research might however have an explanation. A systematic review compared the REST-Q sleep subscale to a series of objective measures of training load (Saw et al., 2015c). However, the validity and reliability of the REST-Q sleep quality subscale has been strongly critiqued (Davis IV et al., 2007), therefore it is perhaps unsurprising that sleep quality was found to have poor sensitivity in the review by Saw et al. (2015c). Sleep quality has also been used as an umbrella term that, until recently, has been poorly defined (Claudino et al., 2019), which may add to the confusion in this area.

The lack of clear guidelines for practitioners constructing custom athlete self-report measures risks vagueness or imprecision in question and response design. For example, 44% of respondents from this study did not incorporate a specific time period for athletes to reflect on their questions, e.g. 'how fatigued are you feeling this morning?' Clarity and specificity of question construction is important and good practice in questionnaire design (Hughes, 2017). Further, respondents indicated that they used a range of response scales, with most using a 10 -Likert scale. Despite the majority (57%) of respondents indicating that they did not know why their scale length had been chosen, longer scales were believed by respondents to increase the sensitivity of their measures. Research has however demonstrated that increasing Likert scales beyond 7 response points does not increase reliability or validity. Likert scales beyond 7 points exceed the discriminatory capacity of the individual, with the optimal number of responses advised to include written descriptors and being between 4 and 7 points (Lozano et al., 2008).

Discussions pertaining to best practice for analysing athlete monitoring data have proposed a variety of methods dependent upon the data type, including: exponential and rolling averages for training load data (Menaspà, 2016; Murray et al., 2017), and linear and non-linear modelling (Gabbet et al., 2017; Robertson et al., 2017). This study has given a high-level picture of which data analysis methods were most commonly utilised in elite sport. It appeared that few respondents used the analytical approaches discussed above, with standard deviations and raw scores most commonly used to assess meaningful change. While this may superficially indicate a failure to follow best practice, it is perhaps a result of time, resource, and/or knowledge constraints, or practitioners needing to adapt their data analysis style to suit coach-friendly requirements (Gabbet et al., 2017; Robertson et al., 2017). It is important to note that given the broad array of sports represented within this survey a wide variety of

monitoring measures were employed. It was therefore deemed impractical and, moreover, beyond the scope of this study, to explore how each individual metric was analysed. Accordingly, future research should examine in more detail why and how certain data analysis methods are employed, and examine how common statistical issues, such as poor data quality, missing data, or misclassified data is dealt with.

Feedback is a cornerstone of an AMS, but processes to feed data back to athletes were not always effective, with 44% of respondents indicating that they felt their athlete feedback was insufficient, consistent with findings reported elsewhere (Barboza et al., 2017; Gabbet et al., 2017). Respondents reportedly had the most frequent conversations regarding athlete monitoring data with the MDT, followed by the athlete, then coach (Table 3), but some respondents never discussed athlete monitoring data with athletes (4%) and coaches (8%). This finding indicates a significant failure of the communication of athlete monitoring data, which may result from either a lack of buy-in from coaches/athletes (Burgess, 2017), or practitioners lacking either time, resource or confidence in analysing and discussing data (Akenhead & Nassis, 2016). Developers of AMS applications should note that feedback dashboards received little use by practitioners when communicating athlete monitoring results, instead they preferred to use face-to-face feedback.

Some limitations within this study relate to biases and the concept of generalisability or transferability. Non-response bias is where the survey fails to represent the population it set out to as a result of a section of the population failing to reply (Sedgwick, 2014). This was controlled for in this study through response deadlines, reminders, and the email invite to participate originating from within the English Institute of Sport to foster trust and transparency in how the data would be subsequently used. Additionally, closed questions were primarily used to keep the survey brief (Haunberger, 2011; Sedgwick, 2014; Silverman, 2010). Athlete monitoring is typically included as a key performance indicator for sporting organisations by their funding agency UK Sport (*How UK Sport funding works | UK Sport*, n.d.; *Scottish Gymnastics: Performance Plan*, 2019).Therefore as sporting organisations within the United Kingdom have access to a bespoke online AMS (*Case study: PDMS*, n.d.), it was felt that where this key performance indicator was present it would help mitigate non-response bias. This survey elicited responses from practitioners working in a broad range of different Olympic and Paralympic sports. Wider transferability within elite sport can therefore be cautiously presumed, especially as some of the study findings are supported by previous research (Taylor et al., 2012). An improved response rate to the survey would however further improve confidence in these findings.

4.5 Conclusion

Consistent with previous research (Taylor et al., 2012), this study found that practitioners in elite sport in the United Kingdom widely employed custom AMS, favouring this over published and validated athlete monitoring methods. Some respondents also indicated that their AMS was implemented without an evidence-based approach, nor a clear rationale for its use, a novel finding given the broad range of sports surveyed. This study has also highlighted continued uncertainty regarding the sensitivity of custom athlete self-report measures, divergence from best-practice data analysis methods in published research, poor perceived athlete adherence, and fragmented feedback processes. In light of these issues, questions remain on how to ensure AMS remain useful and practical for stakeholders, whilst simultaneously enhancing an athlete's experience of and, ultimately, performance in the elite sport environment.

4.6 Practical implications

- Athlete monitoring systems should have a clearly articulated rationale for their use, supported by an evidence-based implementation strategy.
- Expectations of athlete monitoring data feedback and use should be clearly outlined (particularly between coach-athlete-practitioner) to prevent poor communication.
- Assess and address if research-advocated best practice is being followed in custom question and response scale design, and data analysis.

5.0 Chapter Five – The Perceived Value of Athlete Monitoring to Practitioners in Elite Sport

5.1 Introduction

In the previous chapter, current athlete monitoring practices in elite sport were explored. The findings of Chapter 4 indicated that there is widespread use of custom athlete monitoring measures, sometimes without a clear rationale for their use, with feedback between the practitioner/coach/athlete often sub-optimal. This led to concerns about the underpinning scientific rationale, and validity of such measures. Therefore, given the concerns raised in Chapter 4, this chapter aimed to explore whether these issues influenced the perceived value of AMS to practitioners. Understanding the value an AMS can provide is important, because, if the perceived value of AMS is poor, but their use widespread, wider questions are then raised about the utility and efficacy of AMS. This chapter explores two themes which were raised in Chapter 4: practitioners' confidence in their athlete monitoring measures, and the engagement of end-users with the AMS. These themes provide a framework with which to understand the value that practitioners place in their AMS.

Athlete monitoring systems have been promoted as tools that aim to decrease illness/injury incidence and optimise performance (Halson, 2014). Recent research in the area of athlete monitoring has highlighted the utility of subjective athlete self-report measures, session rating of perceived exertion, and objective measures such as heart rate variability and sleep actigraphy (Burgess, 2017; Saw et al., 2015c; Scott et al., 2013). Despite this, aspects of athlete monitoring, such as the use of biochemical measures (Halson, 2014; Thorpe et al., 2017), customised athlete self-report measures (Saw et al., 2017), and the acute to chronic workload ratio (Impellizzeri et al., 2019), have come under scrutiny, primarily for their impracticality, poor validity and methodological rigour. This has led to concerns about the ability of athlete monitoring measures to reliably detect meaningful change, and to subsequently aid with injury/illness reduction and performance enhancement. These issues were highlighted in Chapter 4.4, and the literature (Coyne et al., 2018; Fanchini et al., 2018; Heidari et al., 2018; Jovanovic, 2017).

To date, research in the area of athlete monitoring has primarily involved a more mechanistic investigation, focussing on the 'what and how' of monitoring, with an ongoing emphasis on finding and selecting appropriate monitoring measures (Bourdon et al., 2017; Currell & Jeukendrup, 2008; Saw et al., 2015b). In particular, research has sought the most representative measure of training status (Borresen & Lambert, 2008) in order to satisfy demands to make athlete monitoring time-efficient (Roos et al., 2013; Starling & Lambert, 2018). Arguably however, the reductionism inherent in distilling training status down to single

variables is unlikely to be successful given the individuality and complexity of athletes' responses to training and performance (Coyne et al., 2018; Davids, 2014). Thus, more recently practitioners have been advised to adopt a bespoke multi-factorial model of athlete monitoring that also aligns with coaching requirements (Coyne et al., 2018). Nonetheless, these competing demands to (a) simplify monitoring, but (b) record sufficient data to capture the 'correct' indicators of training status, clearly conflict.

In the pursuit of trying to measure training status, voluminous data is often collected by practitioners. Arguably this reflects uncertainty in athlete monitoring, a lack of confidence practitioners may have in their athlete monitoring metrics, and the inherent reductionist philosophies of practitioners (Starling & Lambert, 2018; Vaughan et al., 2019; Weston, 2018). A mechanistic research approach focussing on the 'what and how' of athlete monitoring, is therefore understandable when trying to alleviate the uncertainty surrounding what to monitor. Arguably, however, this approach has been at the cost of investigating more intangible issues, such as practitioner perceptions of AMS efficacy and confidence and stakeholder engagement/buy-in with athlete monitoring. Simultaneously, these issues have been deemed central to the success of an AMS, from both practical (Akenhead & Nassis, 2016; J. J. Malone et al., 2019; Saw et al., 2017) and theoretical standpoints (Fishbein & Ajzen, 2009).

An AMS can aid in understanding changes in athletic performance (Bourdon et al., 2017), thus reducing subsequent uncertainty when implementing changes to training programmes (Halson, 2014). Poor AMS efficacy may result in practitioners lacking confidence in the ability of the athlete monitoring metrics to detect change. The likelihood of practitioners then being able to positively influence programmatic decisions is probably diminished and the subsequent role of the AMS risks becoming unclear (Coyne et al., 2018). A lack of practitioner confidence in athlete monitoring measures has been previously highlighted in International level football, likely precipitated by the AMS functioning less effectively than expected (Akenhead & Nassis, 2016; Weston, 2018). Similar concerns over AMS efficacy have also been raised elsewhere (Coyne et al., 2018), with the authors describing evidence supporting the efficacy of training load monitoring metrics as "not high." Further, it has been argued that the use of black-box statistical 'golems' to predict injury comes riddled with potential errors (Jovanovic, 2017). To date however, no studies have explored practitioner views on the value of their AMS beyond those in elite football.

Alongside confidence in AMS, a behavioural construct that is frequently cited as vital for the success of athlete monitoring is stakeholder buy-in, i.e. buy-in to monitoring from athletes, coaches, practitioners and management (Akenhead & Nassis, 2016; Burgess, 2017). However, what buy-in is, and how to achieve it has been, to date, poorly defined. In organisational

change contexts, buy-in refers to a continuum of cognitive and behavioural activities related to an individual's commitment to change (Mathews & Crocker, 2014). In a sports science context, buy-in to athlete monitoring could therefore be described as an individual's cognitive (attitude and beliefs) and behavioural (actions) commitment to the AMS. Arguably, buy-in to an AMS could provide a general indication of how or if stakeholders value their AMS.

Research has shown that attaining buy-in to an AMS from both coaches and athletes can be problematic (Burgess, 2017; Saw et al., 2015b). Given the negative attitudes of some athletes and coaches (Akenhead & Nassis, 2016; Burgess, 2017) towards AMS, poor reported buy-in to athlete monitoring is unsurprising, particularly as attitudes have been shown to determine behaviour (Fishbein & Ajzen, 2009). Achieving coach buy-in to an AMS is particularly important. Coaches are primarily responsible for writing and modifying the athlete's training programme and managing training load, in response to changes in athlete health and training status (Halson, 2014). Previously, poor coach buy-in to sports science has been attributed to a failure to translate scientific findings into practice and to monitoring metrics usurping coaching craft (Buchheit, 2017; Eisenmann, 2017). Athlete buy-in to an AMS is also central to its success as without their engagement there is no data to review. Athlete adherence to AMS has however been demonstrated to vary widely (Barboza et al., 2017; Cunniffe et al., 2009), though the individual reasons for poor buy-in are less clear. Broader generalisations regarding engagement differences between individual or team sport athletes, variations in sporting organisation infrastructure, feedback quality/quantity and the favourableness of the coach/athlete relationship have been proposed as possible reasons for poor athlete buy-in (Barboza et al., 2017; Jowett & Cockerill, 2003; Saw et al., 2015a).

Practitioner perception of AMS efficacy has been described in elite level football (Akenhead & Nassis, 2016; Weston, 2018), with limited human resources, sub-optimal coach buy-in, and poor measurement tool reliability cited as key barriers to AMS effectiveness. Beyond elite football, however, there is scant information on whether practitioners across a broader range of elite sports perceive their AMS to function effectively, or on the degree to which an AMS is underpinned by scientific evidence. Practitioner opinions on the efficacy of athlete monitoring are therefore vital in order to aid understanding on AMS utility beyond the "how and what" of athlete monitoring. The perceptions practitioners have regarding the value AMS provides their sporting organisation can also inform research and support the improvement of current athlete monitoring practices. Understanding the current climate surrounding athlete monitoring in elite sport is particularly important when set against growing concerns regarding the efficacy of athlete monitoring (Coyne et al., 2018; Jovanovic, 2017; Lolli et al., 2019b). Thus, the aim of this study was to investigate practitioners' perceptions of AMS value in elite

sport in the United Kingdom. The alternative hypotheses were as follows: *Practitioner confidence will be higher in athlete self-report measures where: (H_1) Practitioners report that there is a scientific underpinning to their AMS and (H_2) practitioners report meaningful changes in their AMS data are acted upon. Higher athlete adherence rates to an AMS will be reported where: (H_3) Practitioners report that coaches provide support to their AMS and (H_4) practitioners report that athletes receive sufficient AMS feedback. Where meaningful change in AMS data is reportedly acted upon: (H_5) Practitioners will report increased coach support for their AMS and (H_6) practitioners will report that there is scientific evidence underpinning their AMS.*

5.2 Methods

5.2.1 Participants

Substantive elements of this methods section were described in Chapter 4.2. For readability purposes they are however repeated here with some study specific additions and amendments. Seventy-five elite sport practitioners were invited to participate in a secure online survey (Online Surveys, JISC, Bristol, UK) about athlete training and monitoring practices in their sport. The return rate was 40%. Respondents were selected through stratified and convenience sampling, with potential respondents contacted via email by their discipline lead at the English Institute of Sport and given links to the survey and participant information. Follow-up reminder emails were sent to non-responders at two and approximately four weeks following the initial invite. Access and written agreements to participants were gained through gatekeepers at the English Institute of Sport. Staff members who were known to work within Olympic or Paralympic sport, but who were not affiliated with the English Institute of Sport, were followed up separately via convenience sampling.

Ethical approval was granted by the University of Winchester Ethics Committee. All respondents received electronic information and a full written explanation of the study and were subsequently given the opportunity to voluntarily agree to complete the survey. Informed consent to participate was given electronically after respondents had viewed the study information. Direct written quotes in the survey are coded to participants, e.g. ‘P1’, and are used to provide more context to the results, as appropriate.

5.2.2 Procedure & Statistics

A password protected link to the survey was electronically sent to the identified practitioners. Any respondents that indicated they did not consent to take part were taken to a separate webpage where no further questions were asked. Respondents that indicated they did not have an AMS in place were directed to the end of the survey, and those that did have an AMS

were asked to complete the full survey. The survey was reviewed for content validity (Stoszkowski & Collins, 2016), by three applied sports science practitioners and a University sports science academic. This resulted in several modifications, with one question removed, two added and several questions altered to enhance their readability. The survey comprised of questions under the broad headings of: (1) data collection, (2) data analysis, (3) feedback of information, and (4) open ended questions on their opinions of monitoring in their sport. Closed questions used Likert-type response scales as presented elsewhere (Vagias, 2006). Cronbach's alpha was established retrospectively on the main data themes to assess the reliability of the survey interpretation (Tavakol & Dennick, 2011). Similar constructs were analysed and yielded the following good to average alphas: data collection (questions 7, 16, 17, 18) α =0.68, CI = (0.39, 0.86), feedback (questions 19, 21, 22, 23) α =0.81, CI = (0.67, 0.90), athlete truthfulness (questions 25 and 26) α =0.79 CI = (0.58, 0.92). A full list of the questions can be found in the Appendices, Chapter 12. The survey was formulated based on discussions between the author of this thesis and the supervisory team and was based on their combined knowledge and expertise and informed by previous research in this area (Taylor et al., 2012).

Statistical analyses were focussed on issues raised in the introduction (Chapter 5.1), i.e. investigating associations between factors that could impact: the confidence of respondents in the AMS, and engagement of stakeholders with the AMS. Using SPSS (V26, Armonk, NY: IBM Corp), the strength of relations between data were tested by Spearman's correlation coefficient, with the significance set at 0.05. Spearman's correlation coefficient was used due to violation of the assumptions of Pearson's correlation coefficient, such as data type (data is ordinal and, therefore, non-continuous) and non-normality of data distribution. Power calculations with $\alpha = 0.05$ and $\beta = 0.80$ returned a sample size of 23, assuming a large effect size of 0.55 (G*Power, V3.1.9.6, University of Kiel, Germany). In order to attain statistical significance and be sufficiently powered, the effect size needed to be ≥ 0.55 and $p < 0.05$.

Neutral responses, e.g. "undecided" (see Appendices for response scales), were included in Spearman's analyses as they formed part of the Likert scale from which participants responded. However, when indicating the degree of agreement/disagreement to a question, any neutral responses were removed from the analysis and the degree of agreement or disagreement reported, e.g. strongly agree and agree were collapsed together for conciseness. Free text data was coded to participants, grouped into key themes that recurred from participant responses and presented alongside participant response rates.

5.3 Results

5.3.1 Background information

Thirty sports science and medicine practitioners completed the survey with fourteen sports represented: Athletics, Para Athletics, Boxing, Canoeing (sprint and slalom), Para Canoeing, Cycling and Para Cycling, Gymnastics, Hockey, Judo, Rowing, Rugby 7's, Sailing, Swimming, Taekwondo and Triathlon. Respondents had 8 ± 5 years (mean ± SD) experience of working in elite sport, and collectively the respondents worked with 599 podium-level athletes, with each respondent working with a different squad within their sporting organisation. The majority (83%, n = 25) of respondents reported using an AMS, with 95% of those employing custom versions of AMS.

5.3.2 Practitioners' confidence in the AMS

Confidence in the sensitivity of the athlete self-report monitoring measures was divided, with 52% quite or very confident of their measures and 48% unsure or not confident. Scientific studies reportedly underpinned athlete monitoring measures utilised by practitioners in 64% of cases, with 24% of respondents disagreeing, and 12% undecided. Where respondents were confident in the sensitivity of their measures, more had a scientific underpinning in place (83%) than did not (17%), with a medium effect size (r_S = 0.398, p = 0.049). The degree of confidence participants had in the sensitivity of their measures was however not significantly related to whether action was subsequently taken where meaningful change observed within the data e.g. modifying training programmes in response to AMS data (r_S = 0.370, p = 0.069).

For those respondents that indicated they had poor confidence in the sensitivity of their measures, 75% (9 respondents) chose to elaborate on their concerns. These concerns primarily related to untruthful reporting practices, and the individuality of athlete responses complicating the identification of meaningful change within AMS data.

> [My confidence varies] on an individual basis, it all depends on the athlete understanding the need for this system, and them being honest. (P2)

> We use the day to day data, but as listed above, are not aware currently of individual meaningful change. (P21)

When questioned on how confidence in their measure sensitivity could be improved, 68% (17 respondents) replied, with suggestions including: improving the engagement and truthfulness of athlete AMS reporting, and the production of best practice guidelines to support the athlete monitoring process: "If the athletes were better engaged this would provide greater multi-disciplinary team (MDT) confidence in the accuracy of reports" (P25); "Guidelines for how to collect data and analyse data" (P5).

Athletes were perceived to be truthful in their AMS reporting practices by 56% of respondents, with the remainder undecided (36%), or in disagreement (8%). Respondents rated which factors they believed influenced the truthfulness of athlete reporting practices (Figure 8). The top three factors were: athlete concern regarding potential consequences for their training (e.g. removal from training), poor athlete engagement with monitoring, and coach expectations.

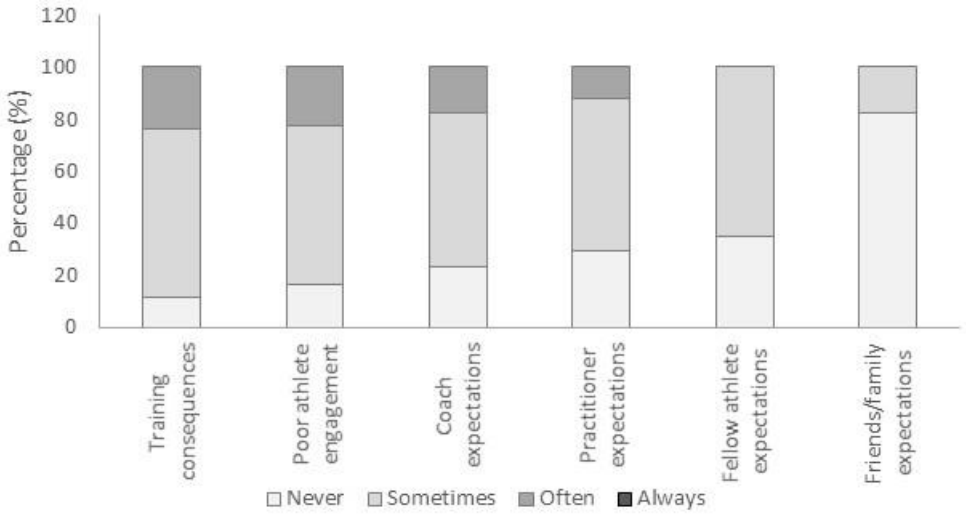

Figure 8. Practitioners' perceptions of what factors primarily influenced the truthfulness of athlete reporting in an AMS.

5.3.3 Engagement of end-users with the AMS

Respondents rated the degree to which they felt supported by various stakeholders to both implement and ensure their AMS was an ongoing success (Figure 9). Providers of the AMS, and fellow MDT (multi-disciplinary team) were perceived by respondents as providing full support to ensure their AMS were successful in 87% and 96% of cases respectively. In comparison, respondents felt fully supported by sport science managers in 74% of cases, and by coaches in 44% of cases. Over half of respondents felt that athletes (56%), and coaches (60%) had sufficient education on their AMS.

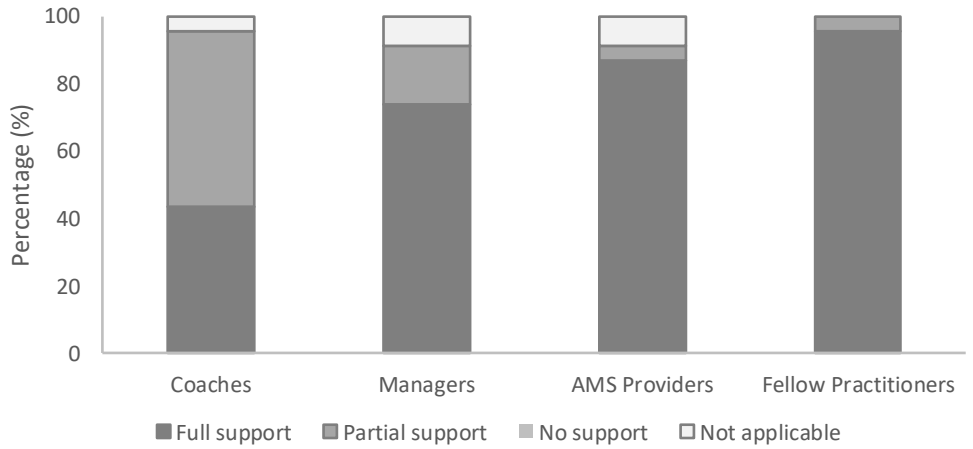

Figure 9. Respondents rated the degree to which they felt supported by different stakeholders to implement and ensure the ongoing success of their AMS.

Respondents were divided over whether action was taken to modify training where meaningful change in monitoring scores was detected, with 44% in agreement, 20% undecided and 36% disagreeing. Where action was taken when meaningful change in athlete monitoring scores was observed, respondents were more likely to have a scientific underpinning to their measures, with the effect size bordering on large (r_S = 0.490, p = 0.013). The degree of coach support for the AMS did not significantly impact whether action was taken when meaningful change in AMS data was detected (r_S = 0.052, p = 0.818).

Reasons given by respondents for not modifying training where meaningful change in AMS data was detected related to coach buy-in, and contextual interpretation and feedback from AMS responses: “The coach has the final say, if they feel they are still able to train then they will” (P2). Coaches don't understand the [AMS] questions…and don't respond to [athlete] answers” (P16). The context of any meaningful change in athlete monitoring scores was key, with one practitioner stating: “I would never pull an athlete entirely on the basis of scores. Would need interrogation incl. athlete + practitioner conversation to understand big picture. Scores (-ve) may be intentional.” (P26)

In relation to expected adherence rates, 67% of respondents indicated that athletes always or very frequently completed their AMS data, with the remaining 33% indicating that AMS completion was only rarely, or occasionally completed. While the majority (61%) of respondents felt that poor adherence could be tied to a specific timeframe, e.g. during competitions, there was no consensus on when this primarily occurred during the training calendar.

There was a non-significant trend towards athletes being more likely to complete the AMS where full support from the coaches was reported by respondents with a medium effect size (r_S = 0.372, p = 0.097). Here, respondents in receipt of full coach support for their AMS reported that 80% of athletes were considered to have good adherence (always or very frequently completing the AMS). In comparison, where coach support for the AMS was partial/none, there was a relatively even split between athletes reportedly having good (55%) or poor (45%) adherence to the AMS. The relation between athlete adherence to monitoring and the perception of athletes receiving sufficient feedback was significant with a large effect size (r_S = 0.675, p = <0.001). When asked how to improve athlete adherence to AMS, respondents highlighted increased feedback needs (particularly led by the coach) as a key area for change, stating: “More frequent feedback [is required] from practitioners and coaches” (P10). “If the athlete reports anything it must be followed up, otherwise the trust in the process is gone” (P19). One respondent inferred increased athlete education was required: “Them [athletes] simply understanding the ‘WHY’” (P2).

Imposing consequences for poor adherence, as well as advantages for good adherence, were given as other methods to promote engagement with AMS: “Write [adherence] into athlete agreement with consequences if not filled in (stick) and modified and individualised training based off it (carrot)” (P8). Nonetheless, one respondent whose sport did impose consequences for poor adherence commented: “Achieve buy-in instead of it being a programme requirement” (P22).

Formalised negative consequences, e.g. removal from training, were imposed for poor adherence to the AMS by 24% of respondents. Good adherence was reported by 67% of those with formal consequences for non-adherence, which is similar to the 63% who also reported good adherence but had no consequences in place. Consequences included: a reduction in one-to-one coaching sessions, preventing athletes from training, no training individualisation and funding being withheld. “[Consequences for non-adherence are] athletes not being allowed to train” (P23).

Exactly half of the respondents felt that athletes’ performance might be compromised if they did not complete their athlete monitoring, with the other half disagreeing. Furthermore, 58% of respondents reported that they worked with internationally successful athletes (defined as those who had medalled at Olympic Games, World Championships/Cups) who did not complete the athlete monitoring required by their sporting organisation.

Overall, 60% of respondents felt that an improvement in athlete monitoring in their sporting organisation was required, with 30% undecided and 10% disagreeing. When given the

opportunity to indicate what improvements they might wish to see, 56% of respondents replied. The most popularly cited suggestions included: improving the evidence base behind the measures used, improving the understanding of the measures and their subsequent analysis and feedback to athletes, integrating data from other sources, e.g. objective measures or illness/injury data, and addressing technical issues with the mobile AMS they were using.

> A better understanding of how best to analyse the data and improved strategies to enhance adherence. Improved methods of feedback to coaches and athletes. (P10)

> Being well organised and comparing the subjective daily monitoring with objective measures such as hydration, weight, resting heart rate etc. as well as GPS data to make decisions informed from all of the data collected rather than looking at them individually. (P20)

5.4 Discussion

Practitioners had mixed perceptions of their AMS. Only 52% indicated that they had confidence in the sensitivity of their athlete self-report measures, with 64% agreeing that their measures had a scientific underpinning. A relation was apparent between practitioners' confidence in the sensitivity of their athlete self-report measures and the measures being underpinned by science, however it only had a medium effect size (r_S= 0.398, p = 0.049). Therefore, H_1 was rejected as despite p< 0.05, the medium effect size resulted in insufficient statistical power. To the author's knowledge, this is the first time that the trend of a lack of scientific evidence underpinning athlete monitoring measures in elite sport has been quantified. Poorly perceived engagement and adherence with AMS from both coaches and athletes was also apparent, exemplified by a significant relation with a large effect size between athletes reportedly receiving insufficient feedback and poor AMS adherence (r_S= 0.675, p = <0.001), with H_4 therefore accepted. These issues were underscored by half of respondents indicating that athlete performance would be compromised if there were no athlete monitoring within their sporting organisation.

5.4.1 Practitioners' confidence in the AMS

While 64% of respondents felt that their athlete monitoring measures had a scientific underpinning, nearly a quarter (24%) disagreed. Given the prolific use of custom athlete self-report measures in elite sport (Burgess, 2017; Taylor et al., 2012), this result is perhaps not surprising. As discussed elsewhere (Saw et al., 2017), the potential lack of evidence-based practice from a quarter of respondents may subsequently negatively impact AMS efficacy. While causality cannot be inferred from the correlations described in this chapter, having a scientific rationale behind athlete monitoring measures was linked to improved respondent

confidence in the sensitivity of their measures, albeit with a medium effect size (r_S= 0.398, p = 0.049). Therefore, it appears sensible for practitioners to ensure that their metrics have an underpinning scientific rationale.

Overall, confidence in the sensitivity of athlete self-report measures was split, with 48% of respondents indicating that they were either unsure or not confident in their measures. Previous research has demonstrated that practitioners have a more favourable perception of the benefits of load monitoring in comparison to coaches (Weston, 2018). However, low practitioner confidence in AMS has been reported in elite football (Akenhead & Nassis, 2016), but was thought to stem from a reduced ability to monitor athletes during competition. In comparison, the primary reasons for poor confidence in this study were given as the perception of dishonest athlete reporting, and difficulty identifying meaningful change within the data.

Difficulty identifying meaningful change in AMS data may imply problems with measure validity (Bourdon et al., 2017; Saw et al., 2017). This study found that having a scientific underpinning to AMS metrics was related to respondents reporting that action was taken, e.g. training programme was modified, where meaningful change was observed, with a medium effect size (r_S= 0.490, p = 0.013). However, despite $p < 0.05$, the effect size was not large, therefore the lack of statistical power meant H_6 was rejected. Nonetheless, this is a factor which should be considered not only to support practitioners' confidence in their measures as discussed above, but to ensure metrics have sufficient scientific rigour to allow meaningful change to be discerned.

Nonetheless, while there was a trend towards practitioners' confidence in the sensitivity of their metrics increasing where action on meaningful change was taken, this finding was non-significant (r_S= 0.370, p = 0.069), therefore H_2 was rejected. Arguably, this demonstrates a statistically non-significant tendency for practitioners with more confidence in their measures to be better able to influence coach decision making. It is unclear from this study why this is the case, but it could be linked to the presence of a scientific evidence base for the metrics. The efficacy, and thus value of an AMS has been previously found to be linked to coach engagement (Akenhead & Nassis, 2016; Saw et al., 2015b). The non-significant relation observed between practitioner confidence and the identification of meaningful change could, as observed by a respondent in this study, be explained by context specificity, i.e. the coach intended for meaningful change to occur and therefore it was inappropriate to modify training. Increasing the sample size or assessing the context in which these decisions were made could further elucidate this relation. Overall, however, it appears that assessing the validity of AMS metrics with in situ methods (Windt et al., 2018), or more novel approaches incorporating

expert opinion (Kyprianou et al., 2019), may improve practitioners' confidence in their measure sensitivity.

Respondents also indicated that their confidence in the athlete monitoring measures was negatively impacted by the perception of untruthful athlete reporting practices, this issue having been described elsewhere (Akenhead & Nassis, 2016; Saw et al., 2015b). Just over half (56%) of respondents from this survey felt athletes completed their monitoring truthfully, with the remainder feeling either unsure, or reporting that athletes were untruthful. Poor athlete engagement and the potential of consequences to athlete's training programme were amongst the factors felt to influence reporting practice (Figure 8). Previously reported reasons for athletes manipulating their responses have included: social desirability bias (Van de Mortel, 2008), perceptions of inappropriate modifications made to training programmes (Duignan et al., 2019b) and avoidance of consequences for non-adherence (Saw et al., 2015b). The manipulation of monitoring responses is reportedly more common in junior rather than senior team members (Duignan et al., 2019b). Nonetheless, little research has explored in detail why athletes choose to behave in this way.

Current approaches to mitigate the problem of untruthful reporting practices, such as athlete education sessions (Saw et al., 2015d, 2017), appear therefore to have limited effect. Implementing a social desirability response scale to adjust for bias (Tracey, 2016) may, in part, tackle these concerns, but simultaneously it risks alienating athletes and propagating an ethos of hostile surveillance (Manley & Williams, 2019). Therefore, a fundamental shift in the culture surrounding athlete monitoring is required in order to change athlete perceptions of athlete monitoring, and simultaneously address practitioner concerns of untruthful reporting practices. Reframing athlete 'monitoring' as a core principle of athlete care (Fisher et al., 2019), with a focus on creating a psychologically safe environment (Newman et al., 2017), should be explored in future research.

5.4.2 Engagement of end-users with the AMS

Enhancing performance has been described as a primary aim for AMS both in this thesis (see Chapter 4) and elsewhere (Bourdon et al., 2017; Saw et al., 2018). However, only half of the respondents in this survey indicated performance would be compromised if no AMS was in place in their sport. When this is paired with 58% of respondents reportedly working with internationally successful athletes who did not partake in the monitoring within their sporting organisation, it inevitably leads to questions about the engagement and perceived efficacy of AMS within elite sport. Figure 9 outlines the degree of support respondents reported they received to implement and run their AMS. Fellow practitioners were the most likely to give full

support for the AMS (in 96% of cases). Managers in the sport were reported to fully support 74% of respondents, but 52% of respondents indicated that they did not have full support for their AMS from their coach. This is higher than the 37% of elite football practitioners reporting coach buy-in as a substantial barrier to the efficacy of athlete monitoring in elite football (Akenhead & Nassis, 2016). Thus illustrating, that poor coach buy-in to athlete monitoring is endemic across a broad range of sports. This study was unable to demonstrate a statistical link between the degree of coach support for an AMS and action being taken where meaningful change was identified in AMS data (r_S= 0.052, p = 0.818), therefore H_5 was rejected. Neither was there a statistically significant relation between coach support and athlete adherence to AMS; however, a trend towards a relation between these two parameters with a medium effect size was apparent (r_S= 0.372, p = 0.097), therefore H_3 was rejected. The importance of coach support for an AMS has been discussed elsewhere, and should not be underestimated (Burgess, 2017; J. J. Malone et al., 2019). Accordingly, where guidelines exist for implementing AMS (Saw et al., 2017), strategies for achieving coach buy-in should also be included.

Research to date has mainly attributed poor coach engagement with athlete monitoring to failures to translate findings from athlete monitoring into clear practical messages for coaches. Other issues have included: inaccessible scientific language/findings, and internal politics caused by a perception of AMS usurping coaching craft in driving targets, funding, and performance assessment (Buchheit, 2017; Eisenmann, 2017; Weston, 2018). Thus, despite coaches and practitioners having similar beliefs regarding the purpose and utility of athlete monitoring (Weston, 2018), these views do not necessarily translate into engagement with athlete monitoring. It appears that athlete monitoring often fails to meet expectation (Akenhead & Nassis, 2016; Roos et al., 2013; Starling & Lambert, 2018), and has the potential to cause internal political conflicts if poorly managed (Eisenmann, 2017). Overall, it is unsurprising that coach buy-in to AMS is poor, particularly if practitioners lack scientific evidence in the measures utilised, as seen in this study and elsewhere (Coyne et al., 2018).

Custom athlete self-report measures, used by 95% of respondents in this survey, are reportedly used in preference to validated athlete self-report measures in elite sport due to their brevity and sports specificity, and are thus believed to positively influence athlete adherence (Taylor et al., 2012). However, as this study and others (Barboza et al., 2017; Saw et al., 2015b) have shown, athlete adherence to AMS is still problematic, despite the use of custom athlete self-report measures. Unfortunately, data for adherence and attrition rates to AMS in elite sport are sparse, and while the figure of 67% of respondents reporting good adherence rates from this study is broadly similar to the rates of 56% and 79% reported elsewhere (Barboza et al., 2017; Cunniffe et al., 2009), it remains unclear whether or not

custom athlete self-report measures positively influence athlete adherence, as within this study there were no respondents using measures that had been published and validated, e.g. REST-Q questionnaire (Kellmann & Kallus, 2016), with which they could be compared.

Perceptions of athlete adherence were, however, significantly related to whether the respondents reported that athletes received sufficient feedback (r_S= 0.675, p = <0.001). This is an important finding, as researchers have previously only proposed a potential relation between feedback and adherence (Barboza et al., 2017). Improving feedback processes within a sporting organisation may therefore provide a mechanism for practitioners to positively influence athlete adherence to monitoring. Just under quarter (24%) of respondents indicated that their sporting organisation imposed consequences for poor athlete adherence to AMS, typically in the form of training privilege removal. As highlighted elsewhere, these practices were negatively viewed by athletes, and often had deleterious effects on their approach to athlete monitoring (Saw et al., 2015b). Conflictingly, while some respondents with no imposed consequences sought to have them implemented, others with consequences in place wanted them removed. These contradictions question the efficacy of coercion as a behaviour change strategy within this context (Michie et al., 2011), and instead may promote fears of a hostile surveillance culture (Manley & Williams, 2019).

Based on the results from this study, it could be argued that AMS have a limited value to elite sport practitioners as only half of respondents indicated athlete performance would be compromised if their AMS did not exist. This is further underlined by 58% of respondents reporting that they had worked with world class athletes who did not complete the athlete monitoring required by their sport. The inevitable questions this insight provokes have been discussed elsewhere (Buchheit, 2017), and more recently doubt has been cast over the ability of AMS to meet aims such as injury prediction (Lolli et al., 2019a). Given the issues raised above, practitioners should review whether their AMS is, or can, meet its aims of reducing illness/injury risk and performance enhancement within their sport, as also discussed in Chapter 4.4. If it cannot, AMS may be better positioned as a tool to reduce the uncertainty associated with performance enhancement and illness/injury prevention (Knight, 1921).

The main limitations of this survey relate to bias and the transferability of findings, as discussed in Chapter 4 section 4.4. The statistical tests might have provided more definitive associations between parameters had there been a larger sample size, but where effect sizes were 0.55 or greater, statistical power with $\beta = 0.8$ was achieved.

5.5 Conclusion

Practitioners working across a range of elite sport in the UK reported their perceptions of AMS efficacy in a secure online survey. Common issues raised included a lack of confidence in the sensitivity of athlete self-report measures and difficulties engaging coaches and athletes with AMS. Some practitioners reported there was limited scientific rationale supporting their custom athlete monitoring measures. Providing sufficient feedback to athletes was statistically correlated with increased AMS adherence. Other measures which may aid AMS use included ensuring monitoring metrics are underpinned by scientific evidence, or utilising methods to assess their validity (Kyprianou et al., 2019; Windt et al., 2018).

5.6 Practical applications

- Where scientific evidence underpins the use of AMS, practitioners using the AMS appear to have increased confidence in the sensitivity of the AMS metrics and be better able to leverage responses to meaningful changes in AMS data.
- Buy-in and engagement of coaches and athletes are vital if AMS are to be valuable to elite sporting organisations.
- AMS are not necessarily needed to develop internationally successful athletes, but half of respondents felt that performance would be compromised without them.

6.0 Chapter Six - Engagement with Athlete Monitoring in Elite Sport

6.1 Introduction

Chapter 5 explored the value that practitioners working in elite sport placed on their AMS. Concerns were noted in relation to some practitioners' confidence in their AMS, the scientific underpinning of some of the metrics utilised and the subsequent engagement of athletes with the AMS. The reasons for poor athlete engagement with AMS were however unclear from both the findings of Chapter 5 and other research in this area (Barboza et al., 2017; Saw et al., 2015b). The engagement of athletes with monitoring is key where AMS are used to support performance optimisation (Saw et al., 2015b). The opinions of end-users has been shown to influence buy-in more than the objectively perceived benefits of an AMS alone (Donaldson & Finch, 2012). Accordingly, Chapter 6 examines the reasons for poor athlete adherence to monitoring in a cohort of elite athletes, in an effort to understand why poor AMS engagement was noted in Chapter 5.

An effective athlete monitoring system (AMS) can positively influence performance through monitoring an athlete's response to loading with that information used to reduce the risk of illness or injury (Abbott et al., 2018; Halson, 2014). However, successfully implementing an AMS can be problematic in elite sport, with end-user buy-in and a reticence to use scientifically validated measures apparent in Chapters 4 and 5 and from other researchers (Fullagar et al., 2019; Saw et al., 2015b; Taylor et al., 2012). This discrepancy between what research advocates and what happens in practice means it is even more important to provide elite sporting organisations with feasible, valid athlete monitoring strategies and that facilitate optimal performance and mitigate athlete maladaptation (Saw et al., 2017).

Recent guidelines for applied sport practitioners (scientific or medical staff) have suggested specific approaches to overcome some of the issues surrounding athlete monitoring (Saw et al., 2017). However, an extension of these guidelines is necessary as many sporting organisations in Chapter 4 were found to have customised, often un-validated AMS (Taylor et al., 2012), which causes problems not addressed in the guidelines. While it may be scientifically desirable to replace un-validated AMS, careful thought is required on whether it is practically achievable, as this may mean disregarding years of accumulated data. An alternative, which may be more palatable but challenging to achieve, is to address the concerns a custom AMS poses in-situ by assessing their reliability and validity (Kyprianou et al., 2019; Saw et al., 2017; Windt et al., 2018). Despite the use of a custom AMS, which arguably increases engagement in comparison to non-customised alternatives (Taylor et al., 2012), it is apparent that practitioners in elite sport still face significant challenges developing commitment and buy-in from end-users (Fullagar et al., 2019). In light of these challenges, expanding existing

guidelines (Saw et al., 2017) to include strategies to promote buy-in and deal with existing AMS problems would further support elite sporting organisations in optimising their AMS (Donaldson & Finch, 2012).

By understanding the perspectives of end-users, new evidence-based strategies can be developed to improve user engagement. AMS buy-in and success is more likely when these opinions are addressed, as they can influence buy-in more than the objective benefits of the AMS alone (Donaldson & Finch, 2012). Research has begun to explore what end-users want from an AMS (Foster et al., 2017; Roos et al., 2013; Starling & Lambert, 2018), but only a small number of elite athletes' opinions have been gathered (Barboza et al., 2017; Saw et al., 2015b). This research has highlighted athletes' need for a user-friendly, cross-platform compatible interface that is not burdensome to complete; however, it has also identified a worrying trend for untruthful or careless reporting in order to meet the sporting organisations' adherence requirements (Cunniffe et al., 2009; Saw et al., 2015b).

Practitioners are often the driving force behind AMS (Taylor et al., 2012), with their scientific knowledge and inter-personal skills relied upon to make the AMS a success (Saw et al., 2015c). However, there is little to no published evidence of the elite sport sector using theoretical behaviour change models to support practitioners in the adoption of AMS. This lack of underpinning behaviour change theory is surprising given that multiple frameworks and taxonomies for behaviour change, its stages and interventions have been proposed (Davis et al., 2015). Recently, researchers have advocated a social ecological approach when implementing AMS (Saw et al., 2015b), but there does not yet appear to be published evidence of this in practice beyond a recent case study using a nutritional intervention to increase bodyweight (Costello et al., 2018). The behaviour change wheel (Michie et al., 2014), an ecological framework for implementing behaviour change interventions could instead provide elite sport practitioners with a structured approach to enable selection of appropriate interventions, and guide their subsequent implementation.

This study aimed to explore a group of elite athletes' perceptions of their AMS. Using a mixed-methods approach it was aimed to utilise this information to inform intervention strategies to support AMS buy-in.

6.2 Methods

6.2.1 Participants

Recruited through convenience sampling, 9 national team female sprint water-sport athletes agreed to take part in this study. The mean age of the athletes was 23.7 ± 2.5 years, with 3.8 ± 2.5 years of their careers spent on a nationally-funded elite sport programme. All athletes

were fully informed, in writing, of the risks and benefits associated with participation, their anonymity was assured, and informed consent was gained. Ethical approval was granted through the University of Winchester Ethics Committee.

The sports in Chapters 6 and 7 were specifically chosen due to the positive working relationship the author of this thesis had with key practitioners and personnel within those sporting organisations. This relationship allowed access to the athletes and their practitioners with collaborations that permitted a personalised and mutually beneficial working relationship. Had this positive working relationship not existed it would have been challenging, if not impossible to undertake these studies.

6.2.2 Design

Following an education session on the AMS, athletes recorded daily health and training monitoring logs for 12 months in a bespoke online platform (*Case study: PDMS*, n.d.), while adhering to their normal training programme. The athlete education session was delivered by practitioners within the sporting organisation and facilitated by the creators of the AMS from the English Institute of Sport. The athlete education session included an initial discussion pertaining to the rationale for monitoring, how the data would and wouldn't be used, and expectation setting. The mechanics of how to use and access the monitoring tool were then discussed in more detail, with live-demonstrations, sign-ups and walk-throughs of the AMS. Athletes subsequently completed a 12-month period of engagement with the AMS which was led by the sporting organisation. Subsequently, 9 athletes were invited to complete a short questionnaire on their AMS, followed by one-to-one interviews with the primary researcher on their perceptions of the AMS.

6.2.3 Method

Quantitative information on adherence rates were extracted from the AMS dataset and analysed. Due to the 2016 Olympic Games, some athletes were not required to complete their monitoring information over the entire 12-month period. Where relevant, this has been indicated in the results.

Semi-structured interview guides (Chapter 12) were developed to aid discussion and allow novel insights to emerge (Braun & Clarke, 2006). Interviews ranged from 14–27 min in length and were digitally audio-recorded, transcribed verbatim, and then re-checked for accuracy. The interviews commenced with athletes completing a brief questionnaire (Chapter 12) to provide a platform for elaboration within the interview. This was followed by a discussion on the athletes' views on monitoring practices within their sport

6.2.4 Data Analysis

The questionnaire results were collated and interview data were analysed thematically, with NVivo 11 Pro (QSR International Pty Ltd., Doncaster, Australia) used to code the interview data. Using an inductive approach, meaningful units of text were attributed to themes (meaning units) and subsequently coded to nodes using the 6 step process described in the literature (Braun & Clarke, 2006). This process was repeated multiple times and the nodes evolved to ensure the questionnaire results were accurately reflected. The nodes were subsequently grouped into lower and higher order themes (

). Finally, athletes were sent the transcribed versions of their interviews and the coded themes. Any comments raised were then considered in the construction of the final thematic analysis. Example athlete quotes are coded, e.g. A01 and used to exemplify findings in the results section.

6.3 Results

Of the athlete's interviewed, 78% were either undecided or disagreed that they received enough feedback from their AMS data (Figure 10a). A further 56% either disagreed or were undecided on whether action was taken when meaningful changes in athlete monitoring scores occurred (Figure 10b). The majority of respondents stated that they were honest in their athlete monitoring responses, with one athlete indicating that they were not (Figure 10c). However, 44% of respondents either agreed or strongly agreed that athlete monitoring feedback helped optimise their training and performance, with 56% undecided (Figure 10d).

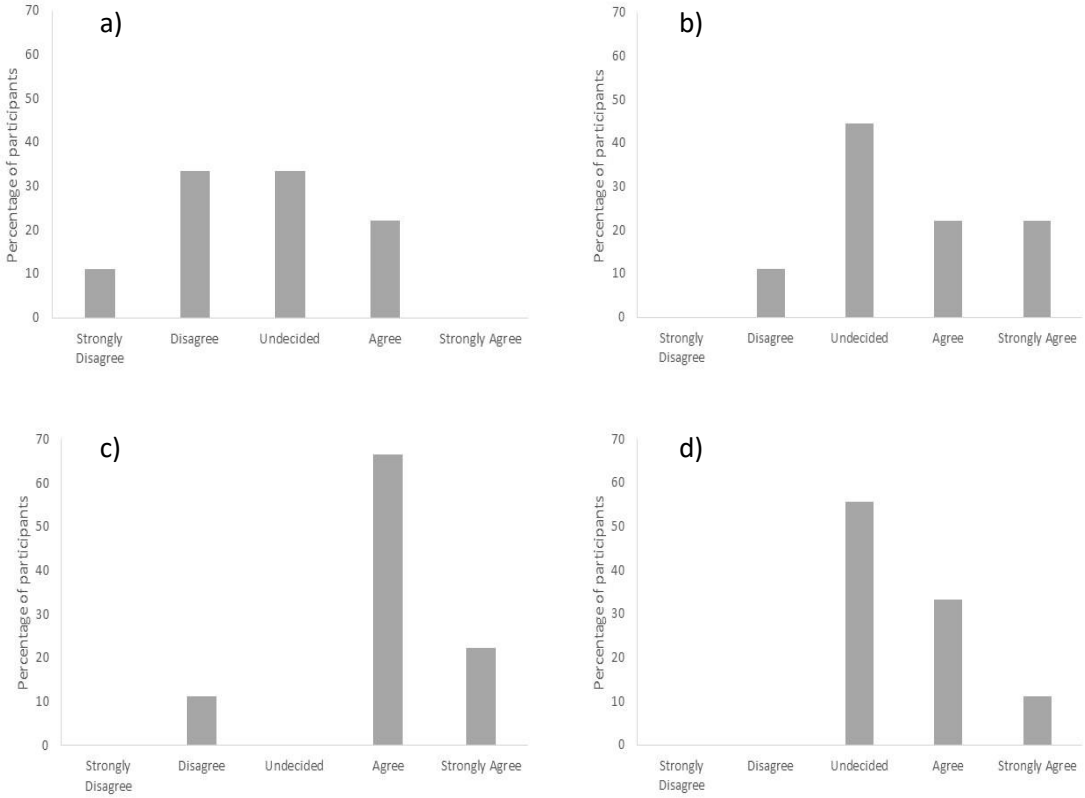

Figure 10. Questionnaire responses by athletes indicating the strength of their feelings towards the following questions: a) "I receive sufficient feedback from the data I enter into my AMS," b) "When there are meaningful changes in my athlete monitoring scores, action is taken." c) "I respond honestly to athlete monitoring questions," and d) "athlete monitoring and feedback helps optimise my training and performances."

Higher and sub order themes are summarised in Table 4, along with the number of meaning units coded from the interview transcripts. The most discussed theme related to feedback and subsequent actions. When the examples of these were analysed, the majority of the remarks were classed as ineffective examples of feedback. Under the Education and Awareness theme, the majority of comments demonstrated a lack of understanding in relation to athlete monitoring. A comparison of negative and positive reflectivity and ownership under the Athlete Approach theme showed that over half were negative comments.

Table 4. The total number of meaning units and athlete sources attributed to the data themes

Higher-order themes	Lower-order themes	Meaning units (M.U.)	Number of sources
Adherence	Habit forming and behaviour change	19	5
	Non-adherence consequences	10	8
	Adherence inhibitors	12	8
	Adherence promoters	16	9
	Subtotal	*57*	
Athlete Approach	Negative reflectivity and ownership	31	9
	Positive reflectivity and ownership	11	8
	Wellbeing definition and impact	28	9
	Monitoring process influences scoring	4	4
	Subtotal	*74*	
Education and Awareness	Lack understanding of monitoring	26	8
	Demonstrates understanding of monitoring	12	5
	Subtotal	*38*	
Feedback and Act	Effective examples	38	8
	Ineffective examples	58	9
	Athlete feedback preferences	18	9
	Subtotal	*114*	
Planning and Design	Additional monitoring	11	9
	Suggested improvements	32	9
	Perceived sensitivity of questions	13	9
	Technical & Equipment issues	12	6
	Subtotal	*68*	

6.3.1 Adherence

Adherence completion rates in the year leading up to the interviews were 62 ± 20%. This figure has been amended to reflect that, due to the competition cycle, 3 of the 9 athletes were not required to complete their monitoring from June 2016 until the August 2016 Olympic Games. Adherence was a high order theme, with athletes making many references to both experiences that have promoted (16 Meaning Units, M.U.; see Table 4), and reduced their adherence to athlete monitoring (12 M.U.). “My adherence has been terrible, like full-stop, because when we started [athlete monitoring] nothing was done with the information. It had no benefit to my training” (A01).

Some athletes failed to see the benefit or value of athlete monitoring unless there was visible use of the information, consequently their adherence was negatively impacted. However, when the feedback loop was completed, and athletes had confidence in the process, the opposite was true. “I was in the routine of doing it [athlete monitoring], and I knew there would be holes in it if I didn’t do it, and it motivated [me] to carry on, because I knew I’d see it back” (A06).

Athletes made frequent references to initial difficulties in establishing the habit of completing athlete monitoring, but how, with time, it formed part of their normal training routine. Disruptions to their normal routine, such as camps or competitions, were reported to negatively impact adherence. Consequences imposed by the sporting organisation for non-adherence were negatively viewed, with a perception that the consequences weren't consistently applied, that they tailed off during the season, and that they could usually be evaded.

6.3.2 Athlete Approach

Athletes demonstrated varied engagement with athlete monitoring, from actively disliking it, through to being indifferent or transactional:

> If they're still giving the feedback, then we're happy to continue. Whereas if they stopped giving the feedback you stop doing it, it just kind of becomes this. Like well you don't do anything so I'm not going to bother. But if they continue to keep looking and checking, we're happy to keep filling it in. (A02)

Or, at the other end of the spectrum, demonstrating self-reflection and engagement with the information:

> I think as I have grown as athlete actually learnt, actually realised that actually I can be using this into my own kind of needs and benefits and stuff like that, I think now I understand it and use it a bit more in my own processes. (A07)

Athletes indicated that they were usually truthful in their athlete monitoring reporting. However, some said they were prone to alter their responses during hard training weeks, "to try and make you believe you're better than what you are," (A07) or if they felt their true response might lead to them being removed from training. Four athletes also felt that the athlete monitoring process served as negative reinforcement of their fatigue levels, and this was a particular concern during competitions, despite a recognition from the athletes that the data during that time would be useful.

6.3.3 Education and Awareness

It was clear that some athletes lacked an understanding of the purpose and benefits of athlete monitoring, with 8 out of 9 athletes having comments coded to this theme. "The coaches do pick up any injuries or anything, and that's why it's sometimes a bit like they already know we've got something sore if we talk to them. Why do we need to put it on this?" (A03)

This lack of clarity was exacerbated by some athletes indicating that they were unsure how to best report, interpret, or electronically access information on the online platform. In particular, they found the reporting of the rating of perceived exertion (RPE) and session duration for

time trials or during competition problematic, indicating that the calculated session RPE was not always representative of the actual training load they experienced. In contrast, some athletes revealed a deeper understanding of the purpose of athlete monitoring, demonstrating self-reflective behaviours or indicating they could recognise meaningful patterns. “Well I think when it comes to injuries it’s quite useful. You can kind of, sometimes you can notice a pattern or there is like something creeping up then you would say oh actually this has happened before” (A07).

6.3.4 Feedback and Act

Athletes identified a broad range of feedback preferences, favouring visual feedback supported by formal or informal discussions. Preferred feedback frequency ranged from weekly to monthly, with a mean of 25 days across all athletes. Athletes were however critical about the feedback and actions taken in light of athlete monitoring data. Feedback frequency and timing did not appear to meet athlete expectations, with some athletes indicating that they believed the data was not looked at:

> In the beginning when we started using it, nothing came of it, so we’d be filling this thing out. And then you’d come in in the morning and they’re like so “how are you today?”, and like well if you’d have just read the thing I’ve already filled out, we wouldn’t have to have this conversation. They obviously didn’t read it. (A01)

Other athletes mentioned that as they had not been unwell, they had not received any feedback and the athlete monitoring information was therefore not useful to them. One athlete also underlined the importance of linking the athlete monitoring data back to training load in order to get a holistic picture of their status. Several athletes reported positive benefits from both formal or informal discussion and exploration of their athlete monitoring data with staff. Those athletes that indicated they could perceive value in athlete monitoring gave examples of where the data had been used to benefit their training and recovery:

> I think because they’ve started applying it to training a bit more, like the actual programme, so they’ll check that what you’ve put in is your perceived kind of output for the week, matches what they wanted…and that they’ll actually talk to you about it and give you a bit of feedback. (A01)

Athletes had contrasting views about actions taken based on athlete monitoring data. Some felt that disproportionate responses were taken when negative changes in athlete monitoring data were observed, or that the scientific robustness behind some of the decisions was questionable:

> Because if you're tired, and you put tired down, they go oh you're too tired today, and I'm like I'm not too tired. There's tired and then where's the limit…as an athlete you don't want to be told not to train. (A03)

Whereas others felt no action was taken when athlete monitoring scores changed. "I've been putting like high fatigue, high fatigue a long time before I'm ill, and it doesn't tend to get hugely picked up on" (A05). The athlete monitoring data appeared to prove particularly useful for athletes who perceived they were on the verge of an illness and aided them in identifying 'niggles' before they became significant issues. Overall the athletes depicted a process that worked inconsistently.

6.3.5 Planning and Design

The majority of athletes (56%) completed monitoring in addition to what was required by their sport. Additional monitoring most commonly comprised training diaries where technical and subjective information was recorded, food diaries, GPS and/or heart rate data. A range of technical issues with the mobile application were apparent, including sign-in issues, the absence of a cross-platform mobile application and problems integrating and accessing the key summary information. Athletes suggested a variety of methods to improve the athlete monitoring process. These included linking athlete self-report measures and training load data, and ensuring historical information was accessible and well presented. They also requested that the daily use and feedback of athlete monitoring information became more visible, and that the sporting organisation consider allowing athletes the option of picking one question each to allow more ownership over the athlete monitoring process. Some athletes requested rephrasing questions to allow comparisons to 'normal,' as they felt this would give a better indication of meaningful change.

6.4 Discussion

Research has provided insights into the scientific and technological components of a successful AMS, e.g. measure reliability/validity, specificity and ease of use (Halson, 2014; Saw et al., 2017). While perhaps intuitive, less has been published on how to achieve desirable behaviours in athletes using an AMS, e.g. consistent, honest reporting. Based on a cohort of elite athletes' perspectives, this study has focussed on exploring which factors may improve or impair AMS implementation. The primary concerns reported were disproportionate training modifications in response to meaningful changes in AMS data, and a lack of athlete feedback.

When meaningful change was identified in their feedback, some athletes expressed concerns about inconsistent or disproportionate training modifications made by staff (Figure 10b). This is perhaps unsurprising given the lack of consensus of what constitutes meaningful change (Robertson et al., 2017) and the concerns raised by practitioners in Chapters 4 and 5 regarding

an inability to correctly identify and act on it. For some athletes (Figure 10c) these concerns gave rise to untruthful reporting in order to circumvent their potential removal from training. Previously, untruthful reporting has only been described where punishments were imposed for poor adherence (Saw et al., 2015b). Custom unvalidated AMS may be at more risk of these behavioural problems as their ability to detect meaningful change can be unknown if their metrics have not been validated (Saw et al., 2017). Practitioners and sports science managers should also consider whether an AMS contributes to creating a culture of hostile surveillance as this can exacerbate behavioural issues and poor perceptions of the AMS, as reported elsewhere (Manley & Williams, 2019). Nonetheless, building a culture of trust with athletes through agreed, transparent and proportionate responses to athlete monitoring data is likely to help combat these issues.

Feedback on their AMS data was reported to be highly valued by all athletes, particularly when it was contextualised and related to training load. This finding was clearer in interview data than the questionnaires (Figure 10a) with the inconsistent results potentially attributable to misinterpretation of questionnaire prompts, or more emotive responses occurring within interviews (Harris & Brown, 2010). Some athletes stated that failure to receive AMS feedback negatively impacted their adherence and perception of AMS efficacy. This supports findings from Chapter 5 where athlete adherence was associated with whether they received sufficient feedback. The reported adherence rate of 62 ± 20% is within ranges previously reported, with a 79% adherence rate in professional rugby players (Cunniffe et al., 2009) and 56 ± 25% in a group of elite judo, swimming and volleyball athletes (Barboza et al., 2017). Previous research has also recognised the need for athlete feedback in an AMS (Barboza et al., 2017; Bourdon et al., 2017), but the powerful transactional relation between adherence and feedback expressed by the athletes, while perhaps unsurprising, has only previously been reported with regards to a sports health surveillance system (Barboza et al., 2017). This highlights the need for sports to ensure that their feedback processes for AMS are practical and that they facilitate the exchange of feedback between staff and athletes (Saw et al., 2017).

When asked how frequently they would like to receive feedback, athletes in this study indicated that approximately every 25 days was acceptable. This was, however, contradicted by feelings of irritation and their perceptions of feedback being ineffective if their daily changes in AMS scores were not scrutinised (Table 4). Obtaining feedback frequency statistics could shed light on these contradictory findings, but as feedback frequency is not indicative of quality, this still may not give a comprehensive picture of how feedback influences adherence (Casas-Arce et al., 2017).

While the need for feedback is becoming increasingly evident, what constitutes acceptable feedback content and frequencies in order to maintain adherence is currently not well described. Previously it has been reported that the majority of elite sports collected (55%) and provided feedback (42%) to athletes on AMS data daily (Taylor et al., 2012), but whether or not this feedback rate positively impacted adherence was not reported. Further, while athlete feedback has been deemed important by recent research (Barboza et al., 2017), details on the desired frequency or content of feedback have not been outlined. Therefore, in order to preserve AMS buy-in, sporting organisations should consider a balance between satisfying the need for athlete requested feedback frequencies, which athletes may under-represent, and the staff workload required for daily feedback (Halson, 2014; Lurie & Swaminathan, 2009; Saw et al., 2017). Furthermore, the content of feedback should contextualise patterns (current vs. historical) and meaningful changes, in order to promote athlete self-reflection. Examples of good feedback practice in other disciplines may help direct practitioners in this area (Nicol & Macfarlane-Dick, 2006).

Despite athlete education sessions preceding AMS implementation, athletes reported that they were unsure how to access and interpret their results. Contrary to previously reported data (Foster et al., 2001; Wallace et al., 2009), athletes also stated that session RPE misrepresented their training loads during time trials and competitions and/or reinforced their fatigue levels. Where this occurs, maintaining the confidence of the athletes in the AMS through discussion of the perceived shortcomings of session RPE and agreeing how to tackle them, e.g. standardised accepted session durations/ratings, and agreed monitoring frequencies around sensitive times (such as competition) may help maintain athlete adherence.

Many athletes also felt that there was a mismatch in feedback expectations between themselves and staff, and that they were unsure of the purpose of the AMS in relation to their performance (Figure 10d). Perhaps as a result of this poor understanding, which has been reported elsewhere (Barboza et al., 2017), athletes indicated that they had modified their AMS scores to improve their own perception of health.

As education sessions are a tool frequently utilised to improve intervention efficacy in elite sport (McCall et al., 2016), it may be advisable to review the value of this intervention and to explore additional or alternative methods, such as incentivisation, policy changes, or utilising experienced athletes to mentor new recruits and model expected behaviours. Behaviour change models can provide further guidance (Michie & Johnston, 2012).

Poor user-experience, a failure to integrate subjective and objective data and to visualise historical data can cause athletes to become disengaged from AMS use. As discussed elsewhere (Saw et al., 2015b, 2017), these issues need to be overcome to provide a basic foundation for a serviceable AMS. To promote continued engagement with the AMS it is advisable for it to become routinely utilised within the sport. Performance reviews, video/technical analysis, (in)formal coach/athlete discussions, scheduling and routine training programming, can provide avenues to regularly interact with the AMS (Roos et al., 2013). Exploring the use of personalised questions for athletes, incorporating behaviour change theory, promoting reflective behaviours and providing information and advice through the AMS may further support engagement through promoting athlete autonomy (Deci & Ryan, 2002; Higgins, 2016).

As multiple barriers to AMS implementation have been reported (Saw et al., 2015b), the next step in AMS evolution may be the application of the methodical approach that a theoretical behaviour change model can provide. While primarily targeting athlete behaviours, there may be utility in broadening the scope of any behaviour change strategy to include other staff members (Michie et al., 2011; Saw et al., 2015b). Behaviour change models could help identify the most effective methods to enhance AMS buy-in, potentially saving time, money and political goodwill (Michie et al., 2014). Furthermore, an underpinning theory-driven strategy to promote successful AMS implementation has the potential to support AMS buy-in further through increased intervention effectiveness (Davis et al., 2015).

A recent research focus on AMS has produced evidence for its utility in reducing injury/illness risk (Drew & Finch, 2016), and barriers to implementation (Saw et al., 2015b). A broad multi-level approach has been suggested to combat these barriers (Saw et al., 2015b), and, where possible, this is advisable. However, resource limitations in elite sport may dictate a more targeted approach. Through understanding what factors significantly impact athletes' engagement with AMS, targeted interventions to promote AMS use and behaviour change can be used, thus reducing the time and resource burden of a broader multi-level approach (Michie et al., 2014). A periodised approach to both AMS use, the provision of feedback and the interventions employed may help alleviate 'at risk' periods of poor adherence, e.g. during competitions.

A recognised limitation of this research is transferability beyond the specific context of this study. This can therefore make it difficult to transfer the findings beyond similar settings; however, as other researchers have reported comparable results (Barboza et al., 2017; Saw et al., 2015b), it does appear that some of the issues identified in this study may impact athletes in other sports.

6.5 Conclusion

When completed truthfully, consistently, and in line with expectations, athlete monitoring information can trigger wider conversations to support prevention of illness/injury and optimise performance. However, behavioural issues highlighted in this study may prevent this from occurring unless addressed with appropriately timed and selected interventions. If AMS implementation is planned alongside behaviour change tools, this could reduce the need to rely on the inter-personal skills of practitioners to promote AMS buy-in, lessening the time and resource burden commonly encountered when implementing a new AMS (Michie et al., 2014; Saw et al., 2017; Sinnott et al., 2015). The use of a planned and periodised approach to AMS use, feedback and intervention implementation may further support the successful use of AMS.

6.6 Practical Applications

- Integrating the use of AMS into daily practice through methods such as coach discussion and video analysis should support athlete engagement with AMS.
- Consider undertaking a periodised approach to AMS use and feedback.
- Ensure clear expectation management on the role and capabilities of an AMS, along with feedback frequency, this could further help practitioners maintain buy-in from athletes.

7.0 Chapter Seven – Case Study: An Intervention to Address Athlete Monitoring Adherence

7.1 Introduction

In Chapter 6, the perceptions a cohort of elite athletes had of their AMS was explored. As identified in Chapters 5 and 6, engagement of athletes with their AMS was problematic, and Chapter 6 provided further insight and reasoning into why this poor adherence may occur. The preceding chapters have outlined the important role that AMS can play in elite sport and some reasons for poor engagement with them. This chapter therefore aimed to explore if (i) it was feasible to implement a behaviour change intervention to increase AMS adherence within an elite sporting organisation and (ii) if athlete adherence could be subsequently improved as a consequence of the behaviour change intervention.

Athlete monitoring has been described as the process of collecting, analysing and providing feedback on measures relating to training load, athlete wellbeing, adaptation and fatigue status, with the aim of optimising performance and minimising undesirable outcomes such as injury or illness (Bourdon et al., 2017). Athletic performance is particularly important in the elite sport environment where high training loads and limited recovery periods increase the risk of negative performance and health outcomes (Halson, 2014). Further, performance-contingent funding in elite sport creates a high-stakes environment that can dictate success of both the athlete, the sporting organisation, and personnel working within it (*How UK Sport funding works | UK Sport*, n.d.). To minimise the risk of poor outcomes, it is therefore important to ensure that athlete monitoring in elite sport is effective, and that it is able to provide elite sports personnel with an evidence-base to inform programmatic decision-making.

Elite sport has seen an exponential increase in the volume of athlete monitoring undertaken in recent years (H. R. Thornton et al., 2019), accompanied by a concomitant rise in academic research (Figure 1) in this area (Burgess, 2017; Coyne et al., 2018; Saw et al., 2015b). Arguably, this increase in interest has been fuelled by improvements in the theory and practice of scientifically monitoring athletes (Halson, 2014), alongside the advent of big data (Baerg, 2017), and wearable technology (Cardinale & Varley, 2017). Despite the widespread use of athlete monitoring tools demonstrated in Chapter 4 and by researchers (Taylor et al., 2012), the perceived efficacy of monitoring has, to date, only been reported in premiership football. Here, researchers reported that load monitoring was predominantly perceived positively by coaches and practitioners (Weston, 2018), but actual monitoring effectiveness was perceived to be poorer than expected effectiveness by elite football practitioners (Akenhead & Nassis,

2016). Chapter 5 in this thesis was able to support these findings and extend them to include a broader range of elite sports. These are amongst the first insights into the perceptions of efficacy of athlete monitoring in elite sport, highlighting some concerns regarding the efficacy of AMS for elite sport practitioners.

Chapter 4 highlighted that the day-to-day administration of an AMS is usually delivered by sports science practitioners. However, the overall vision and direction of the AMS is typically led by coaching management and/or performance directors within the sporting organisation (Roos et al., 2013; Starling & Lambert, 2018). The type of leadership displayed by these personnel, i.e. how leaders influence their personnel to achieve a common goal (Fletcher & Arnold, 2011), can impact subsequent success within the sporting organisation (Fletcher & Wagstaff, 2009). Therefore, the presence of effective leadership within a sport can arguably influence AMS uptake. Both within this thesis and more broadly within the literature the role of leadership in driving the success of the AMS has not previously been a focus. Prior research in the area of leadership in elite sport has however made recommendations on the behaviour traits required by effective leaders in elite sport (Arnold et al., 2012), with different leadership styles highlighted that were felt to be effective, such as transformational (M. J. Smith et al., 2017), and bright and dark side leadership (Cruickshank & Collins, 2015).

Reasons for the poor perceptions of AMS efficacy found in Chapter 5 and by other researchers include: poor buy-in of coaches and athletes to the AMS (Weston, 2018), measurement issues (Saw et al., 2015b), inappropriate data analysis techniques (H. R. Thornton et al., 2019), and inadequate feedback processes (Barboza et al., 2017). While each of the constructs outlined above contributes to whether an AMS is successful, the relative importance of each construct remains unclear. However, without first achieving buy-in from athletes and coaches, there will be no athlete monitoring data to analyse, nor feedback to give to athletes. Accordingly, achieving buy-in has been recognised as an antecedent to success for AMS (Akenhead & Nassis, 2016; Saw et al., 2017).

The concept of buy-in, while perhaps implicitly understood (Saw et al., 2015b), has been poorly defined in the elite sport context. In organisational change, buy-in is defined as a continuum of cognitive and behavioural activities related to an individual's commitment to change (Mathews & Crocker, 2014). In the elite sport context it is perhaps better described as an individual's cognitive (attitude and beliefs) and behavioural (actions) commitment to the AMS (Fishbein & Ajzen, 2009). The term engagement is quite often used interchangeably with buy-in when discussing AMS (Duignan et al., 2019b; Saw et al., 2017). However, engagement with an AMS

can be operationally defined as a move towards a more informed and reasoned involvement with the AMS, with adherence – the percentage completion rate of an AMS – an indirect measure of engagement (Budd et al., 2017).

Where researchers have observed poor buy-in to an AMS, causes have been attributed to reasons such as athletes receiving little or no feedback (Barboza et al., 2017) and a hostile surveillance culture (Manley & Williams, 2019). A failure to translate scientific findings into practical applications and a fear of athlete monitoring metrics usurping coaching craft have been highlighted as issues impacting coach buy-in (Buchheit, 2017; Eisenmann, 2017). Many of the solutions proposed to improve buy-in, such as athlete education (Saw et al., 2017) and more visible usage of AMS in practice (Duignan et al., 2019b), have face-validity; however, there appears to be a lack of a systematic or theory-driven approach to address poor buy-in, where it exists. As buy-in has been identified as both problematic to achieve and sustain (Fullagar et al., 2019), but also central to the success of an AMS (Saw et al., 2015b), it is perhaps surprising that little research has addressed a systematic approach to gaining buy-in of athletes and coaches to AMS. For example, current guidelines on ascertaining AMS feasibility refer to ensuring buy-in is gained, but provide the practitioner with no meaningful method of how to achieve it (Saw et al., 2017). Thus, while researchers have identified poor buy-in as a barrier to AMS implementation (Saw et al., 2015b), the application of any systematic approach or theory to successfully achieve stakeholder (athlete and coach) buy-in is notably absent from research.

Behaviour change techniques have been referred to as systematic procedures that are part of a wider intervention designed to change behaviour (Michie et al., 2015). Many different theories or conceptual frameworks surrounding behaviour change exist (Davis et al., 2015). This can make it challenging to select appropriate behaviour change technique(s) or frameworks to implement. Nonetheless, one such behaviour change technique, the behaviour change wheel, has been extensively researched and is arguably more coherent, comprehensive and better linked to models of behaviour change than other behaviour change frameworks (Michie et al., 2011, 2014). The behaviour change wheel has also been previously successfully implemented in an elite sport environment (Costello et al., 2017, 2018).

The behaviour change wheel is underpinned by the COM-B model, a theory of behaviour change. The COM-B model (Capability, Opportunity, Motivation and Behaviour) identifies behaviours that could be targets for behaviour change interventions, as it assumes that for any behaviour to occur, i.e. adherence to an AMS, there must be capability, opportunity and

motivation in order to do so (Michie et al., 2011). Using the model, users can explore psychological theories relating to capability, opportunity or motivation to perform a behaviour, which in turn helps them understand why certain behaviours occur. Once the reason for a behaviour is ascertained, the COM-B model allows practitioners to systematically assess which item(s) on the COM-B model could be modified to influence the intended behaviour. Through using the COM-B model, the behaviour change wheel is unique amongst behaviour change theories in providing both an ecological perspective to solve behaviour change problems and a toolkit with which to do it. This is relevant, as the need for a multi-factorial and, moreover, a practical approach to address AMS implementation issues has been previously identified (Saw et al., 2015b). A version of the behaviour change wheel underpinned by the COM-B model is shown below (Figure 11).

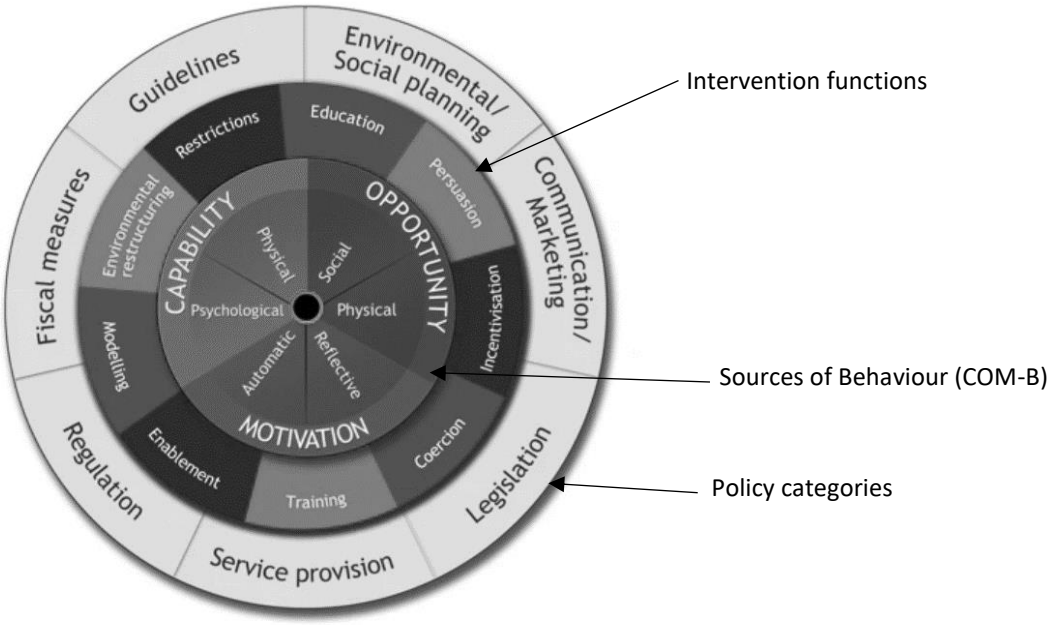

Figure 11. The Behaviour Change Wheel adapted from Michie et al. (2014). The layers of the circle refer to policy categories, intervention functions and sources of behaviour, the latter being based upon the COM-B model.

To date, research within the area of athlete monitoring has tended to focus on improving micro-components of the AMS, such as: the technology (Robertson et al., 2017; Saw et al., 2017), the measures collected (Crowcroft et al., 2017), and the data analysis techniques used (H. R. Thornton et al., 2019). An ecological approach allows consideration of the athlete and their environment. This shifts the research focus from solely the mechanics of the AMS, to a broader perspective that encapsulates the athlete, their support team and the wider context in which the AMS is employed. The use of an ecological lens, i.e. the athlete and their environment, versus a more reductionist approach, i.e. the athlete in isolation, is mirrored in

other research strands. For example, the wider ecological environment has been considered in athlete talent development (Henriksen et al., 2010). In relation to AMS and AMS buy-in in elite sport, a need for such an ecological approach has been identified (Saw et al., 2015b). Currently however, there is little pre-existing guidance for how to modify or achieve AMS buy-in (Saw et al., 2017). The behaviour change wheel provides a potentially realistic and practical method to improve athlete buy-in with AMS in elite sports (Michie et al., 2014). Therefore, the aim of this study was to assess the practicality of implementing a behaviour change intervention over a 6-month period within an elite sport organisation, in this instance a combat sport. A secondary aim was to assess the degree to which the behaviour change intervention was able to increase athlete adherence to their AMS. The hypotheses are outlined below, with testing of the alternative hypothesis H_2, contingent on H_1 being accepted. *H_1: The majority of the behaviour change targets (≥75%), identified using the behaviour change intervention will be fully implemented. H_2: The behaviour change intervention will increase athlete monitoring adherence rates.*

7.2 Methods

7.2.1 Participants

Recruited through convenience sampling, 3 members of the coaching and coaching management team, and 8 national team age group athletes from a combat sport agreed to take part in this study. All participants were internationally competitive in age-group competitions at the time of the study. The mean age of the athletes was 20.1 ± 2.0 years, and the coaching team 43.6 ± 10.0 years. Due to competition requirements, one athlete was not available to complete the post-intervention interviews. All athletes were fully informed, in writing, of the risks and benefits associated with participation, their anonymity was assured and informed consent was gained. Ethical approval was granted through the University of Winchester Ethics Committee.

7.2.2 Design

A mobile application based AMS had been in place for approximately one year prior to this study taking place, with the athletes well habituated to its use. Athletes were expected to complete the AMS daily. Athletes and coaches were invited to attend one-to-one interviews with the author of this thesis regarding their views on their AMS pre and 6 months post a behaviour change intervention. Interviews were held at the athletes' training location. Following the initial interviews, the main themes raised by all participants were identified, anonymised and then discussed with the coaching staff. This occurred as part of a workshop that aimed to design a behaviour change intervention to be implemented within the sporting organisation. In this workshop, the behaviour change wheel framework was used to map

stages of behaviour change strategies to the COM-B model (Michie et al., 2011). Potential behaviour change targets were then systematically assessed to ascertain which item(s) on the model could be modified to bring about an increase in AMS adherence rates (Michie et al., 2014). This culminated in the design of a range of intervention strategies that all staff believed could be feasibly implemented.

7.2.3 Procedure

Using an inductive approach, semi-structured interview guides (Chapter 12) were developed to aid discussion of participant's views on their athlete monitoring system. Interviews focussed on both the athletes' and coaching teams' views on athlete monitoring practices within their sport. Indicative areas explored in the interviews included the relative value of the AMS to the participant, adherence levels to monitoring, and perceptions of the feedback from the data. Post-intervention interviews included an additional discussion regarding the impact and perceptions of the behaviour change intervention. Interviews were digitally audio-recorded, transcribed verbatim, and then re-checked for accuracy and ranged from 4–17 min in length. Daily data on adherence was downloaded from the AMS mobile application for the duration of the intervention period (Figure 12).

7.2.4 Intervention

Following the pre-intervention interviews, the behaviour change wheel (Michie et al., 2014) was used to identify appropriate behaviour change techniques through an eight-step process. The intervention workshop and an informal follow-up discussion with the coaching team gave the final direction and confirmed the proposed content of the intervention.

The intervention strategies identified through the workshop were implemented by the coaches, with a lead coach identified as having responsibility for the process. The lead coach made a concerted effort to implement the targets identified in Table 6. For example, this included upskilling athletes in the use of the AMS, via completion of a series of 1:1 athlete education sessions on the AMS. Use of the AMS was also weaved into daily practice via instigating regular conversations with athletes regarding their data (Table 9). Additionally, athletes were provided with monthly written feedback reports and were frequently reminded both via email and in person to complete their athlete monitoring.

It was not deemed feasible nor appropriate for the author of this thesis to implement the intervention as she was not working directly in the sport, nor did she have established working relationships with all members of the team. Therefore, the implementation of the behaviour change intervention was completed by the coaching team, but initial discussions with the

author of this thesis guided this process. Informal conversations giving updates on the progress of the intervention were held approximately fortnightly and in person between the author and the coach leading the intervention. A 6-month period to implement and then subsequently assess the progress of the intervention was agreed, as it was felt reasonable to attempt to implement all targets during this timeframe, whilst also corresponding to the mean timeframe of interventions reported in the literature (Noar et al., 2007). The steps of the behaviour change wheel (Michie et al., 2014), which informed the behaviour change targets (Table 6) identified in the intervention workshop are summarised below:

Step 1, Define the Problem in Behavioural Terms: The problem identified by the coaching team was poor professionalism from athletes in relation to athlete monitoring. Professionalism was described by the coaches as being exemplified by poor athlete adherence to their AMS. This poor adherence occurred in both the training centres, at camps/competitions and at home. The expectation was that athletes should complete their athlete monitoring daily.

Step 2, Select Target Behaviour(s): A long list of potential behaviours relevant to solving the problem were generated by analysing pre-intervention interview data (Table 5), and informed by research (Saw et al., 2015b). These behaviours were prioritised in relation to their potential utility to change and impact behaviour.

Step 3, Specify the Target Behaviour(s): The list of potential target behaviours identified in Table 5 were then specified in more detail in Table 6, e.g. Who does the behaviour? What does the behaviour involve?

Step 4, Identify what needs to change: The identified target behaviours were then linked to the COM-B model with the aim of deciding what needed to change in order to bring about increased adherence from the athletes towards their AMS (Table 6).

Step 5, Identify Intervention Functions: Based upon the links between the COM-B model and the target behaviours outlined in Table 7, potential intervention functions were identified and assessed in relation to each APEASE (Acceptability, Practicability, (Cost) Effectiveness, Affordability, Safety/Side-Effects, Equity) criterion, with a summary provided in Table 7. While it is important that any intervention be effective, the APEASE criteria are used to design and evaluate the potential utility of interventions with reference to a wider social context (Michie et al., 2014). Most of the proposed interventions were felt to meet the APEASE criteria, but in some interventions the criteria were felt to be met to a lesser degree (see Table 7).

Step 6, *Identify Policy Categories* and *Step 7, Identify Behaviour Change Techniques:* Finally, policy categories were linked to intervention functions*,* and behaviour change techniques matched to the individual behaviour change functions.

Step 8, Identify Mode of Delivery: The modes of delivery agreed for the behaviour change interventions were a combination of individual and group face-to-face sessions, phone-calls and mobile phone application use. All were felt to meet the APEASE criteria, but there were some concerns whether one of the coaches would want to switch from using pen and paper to the mobile application.

7.2.5 Data Analysis

The interview data were analysed thematically, with NVivo 11 Pro (QSR International Pty Ltd., Doncaster, Australia) used to code the interview data. Interviews were grouped for thematic analysis as either pre or post intervention interviews, with the same thematic analysis approach described below applied to both interview groups. Using an inductive approach, meaningful units of text (meaning units) were attributed to themes and subsequently coded to nodes. This process was completed in line with recommendations from the literature, as described by Braun and Clarke (2006). This process was repeated multiple times and the nodes evolved to ensure the interviews were accurately reflected. The nodes were subsequently grouped into lower and higher order themes (Table 8 and Table 9). Finally, the transcribed versions of their interviews and the coded themes were shared and discussed with participants. Any comments raised were then considered in the construction of the final thematic analysis. Participants were coded C1 to 3 for coaches and A1 to 8 for athletes, to ensure anonymity.

Table 5. Examples of candidate target behaviours that could improve athlete adherence in relation to their monitoring system. 4 = Very promising, 3 = promising, 2 = unpromising but worth considering, 1 = unacceptable

Targeted Behaviours	Impact of Behaviour Change	Likelihood of Changing Behaviour	Spill-over Score	Measure-ment Score	Total Score
Athlete:					
- Increase athlete monitoring knowledge and value of AMS	4	3	3	2	12
- Reflect on athlete monitoring data in context of their training and broader day-to-day life	4	2	3	1	10
- Increase the number of times athlete monitoring data is viewed	3	3	3	3	12
Staff:					
- Increase athlete monitoring knowledge and value of AMS	4	3	3	2	12
- All staff to regularly remind athletes to complete athlete monitoring	3	3	2	2	10
- Give more feedback to athletes, including weekly case conference, monthly feedback and performance profile and tell athletes how the data is being used to inform their training plan	4	3	4	3	14
- Implement consequences for poor professionalism	3	4	2	2	11
- Implement positive reinforcement for good professionalism	3	4	2	2	11
- Implement weekly case conferencing where athlete monitoring results are discussed then shared (as applicable)	3	3	3	4	13
- Upload athlete videos of technical skills to AMS	4	3	2	4	13
- Promote athlete self-reflection on their athlete monitoring data.	3	2	3	1	9
- RAG rate technical skill videos on AMS	4	3	2	4	13
- Change expectations of monitoring completion frequency	3	2	2	4	11
- Match and training schedule uploaded to AMS so athletes can see both training session and matches	2	2	2	4	10
- Enable capability for athletes to securely input their scores from a communal mobile device	3	3	2	4	12
- Request developer to consider methods of gamifying the app to make it more appealing to Generation Z.	3	2	2	2	9

Table 6. Specification of Target Behaviours and COM-B Behavioural Analysis. Psy = Psychology, Phys = Physical, Soc = Social, Rfl = Reflective, Aut = Automatic

Target Behaviour	Who	What	When/How often	Where	With whom	COM-B
1. Increase athlete knowledge of value of monitoring	Coaches	Verbal discussions/written information	At start of intervention as part of an education session / ongoing verbal discussions	Training location	Athlete	Capability – Psy Opportunity – Soc Motivation – Rfl & Aut
2. Increase coach's knowledge of value of monitoring†	Lead coach	Verbal discussions/written information	During weekly case conferences and ad hoc conversations between staff members	Training location	Coaches	Capability – Psy, Opportunity – Phys Motivation – Rfl & Aut
3. Conduct weekly case conferences which then forms part of athlete feedback	Coaches	Verbal discussions/written information	Weekly	Training location	Coaches	Opportunity – Phys Motivation – Aut
Improve and increase feedback to athletes*	Coaches	Verbal discussions / written information/In-app data summary	Minimum weekly during intervention	Training location/via AMS	Athletes	Capability – Phys & Psy Opportunity – Phys Motivation – Aut
4. Upload and RAG rate technical videos in AMS*	Coaches	Verbal discussions/written information	Weekly	Training location	Interface with AMS online	Capability – Phys & Psy Opportunity – Phys Motivation – Aut
5. Put in place consequences for non-adherence, e.g. removal of 1:1 training†	Coaches	Removal of 1:1 coaching session if adherence is below poor/Implementation of a display leader board to show adherence rates	Weekly updated	Training location	Athletes	Motivation – Aut
6. Increase reminders to improve adherence	Coaches	Verbal reminder to athletes, Push notifications sent to phone, emailed feedback reports	Daily through to monthly reminders as appropriate	Training location/ online	Athletes	Opportunity – Phys & Soc Motivation – Aut

**Behaviour change target not implemented. †Behaviour change target partially implemented*

Table 7. Identification of Interventions against APEASE (Acceptability, Practicability [Cost], Effectiveness, Affordability, Safety/Side-Effects, Equity) criteria

Intervention Function	Target Behaviour	Does the intervention function meet APEASE criteria?
Education	Educate athletes on value of AMS	Yes
	Educate/train coaching team to:	
	Access AMS online and navigate app	Yes, but may encounter some resistance
	Upload RAG rated videos to AMS	Yes, but may encounter some resistance
	Upskill coaching team on value of online monitoring	Yes, but may encounter some resistance
Persuasion	Expectation set that coaches will be aware of AMS data prior to case conference and will have uploaded/RAG rated videos	Yes
Incentivisation	Put in place leader board to advertise good adherence	Yes
	Promote feedback sessions to athletes as a reward for adherence	Yes
Coercion	Remove 1:1 training sessions if adherence poor	Yes – but possibility to not go as planned
Training	Educate/train coaching team to:	
	Access AMS online and navigate app	Yes, but may encounter some resistance
	Upload RAG rated videos to AMS	Yes, but may encounter some resistance
	Upskill coach on value of online monitoring specifically	Yes, but may encounter some resistance
	Educate athletes on value of AMS	Yes, but may encounter some resistance
Environmental restructuring	Time apportioned weekly for case conferencing	Yes
	Athlete monitoring data discussed at case conferences	Yes
	Online app used during case conferences	Yes
	Value of monitoring discussed at case conferences	Yes
	Athletes reminded to complete athlete monitoring prior to feedback session and ad hoc	Yes
	Time apportioned during week to discuss results from case conference with athletes individually as well as ongoing ad hoc discussions	Yes, need to embed this in culture maybe tricky
	Provide iPad to allow athletes to complete athlete monitoring prior to start of training sessions	Yes, may run into difficulties getting done in timeframe
Modelling	Allow opportunities for athletes to see each other complete athlete monitoring and see each other getting feedback and 1:1 sessions when adherence is good	No – may have privacy issues, needs to be athlete driven
Enablement	Provide iPad to allow athletes to complete athlete monitoring prior to start of training sessions	Yes, may run into difficulties getting done in timeframe

7.3 Results

Table 8 and Table 9 summarise the higher and lower order themes from the pre and post intervention interviews, with representative meaning units used to exemplify the various themes. The results of the behaviour change intervention are demonstrated through athlete adherence rates to the AMS in Figure 12 and via insights from the post-intervention interviews in Table 9. Results of the thematic analyses are shown in the pre-intervention interviews (Table 8) or post-intervention interviews (Table 9), below.

7.3.1 Pre-intervention Higher-Order Interview Themes

Each of the following sections outlines the results from thematic analysis of the pre-intervention interviews displayed in Table 8. Within the tables example quotes are attributed to the different higher and lower order themes, along with the total number of meaning units, and number of sources.

Application of Athlete Monitoring

The coaching team felt that the AMS had the potential to be valuable to help inform their decision making, both to enable performance optimisation and in illness/injury prevention (Table 8). Nonetheless, they indicated that their AMS was not yet able to fully deliver on those aims. Athletes reported that they could mostly see the value of the AMS, particularly for their coaches, but not all felt that the AMS provided value to them.

The AMS was felt by the coaching team to have a role in developing their athletes, through building professionalism via educating athletes on how their bodies respond to training and non-training stressors, and through creating the habits that they would need in their athletic careers. Both coaches and athletes stated that the data from the AMS was utilised to inform decision making around training programming, particularly where there was concern about maladaptation.

Attitude Towards Monitoring

Athletes were very aware of differences between the coaches' approaches to the AMS (Table 8). Athletes indicated that most of the coaches were very engaged with the system. However, while one out of the three coaches supported the use of the AMS, they did not employ it in day-to-day practice, preferring instead to revert to their own preferred monitoring methods. Athlete buy-in with the AMS was also highlighted as problematic by the athletes themselves, as well as by the coaching team. Generally, the coaches perceived

that the athletes were truthful in their reporting practices, but athletes reported that while they were mostly truthful, they were less honest if forced to fill in data retrospectively, or if they had poor motivation to train. The motivation to complete the athlete monitoring varied widely, with some athletes clearly more engaged with the AMS than others (Table 8).

Communication

Athletes deemed AMS feedback to be sporadic, with some athletes indicating that their scores had resulted in conversations with coaches regarding their health, and others indicating that this never happened (Table 8). Athletes did not appear to find great utility in the data summary that was provided by the mobile application, nor did they register it to be a form of feedback. The majority of athletes indicated that the coaches looked at their athlete monitoring data; however, they felt that there was little transparency around how subsequent training programme decisions were made in light of their AMS data.

Measures

Athletes generally described a stop/start approach to completing athlete monitoring, where they completed their monitoring reasonably consistently for a period of time, but then typically stopped, perhaps during a specific time period such as a holiday, or perhaps due to forgetfulness. Both athletes and coaches reported that the mobile application itself was easy to use and took very little time to complete. Despite the minimal time burden associated with the mobile application, some athletes reported that it was not as interesting or engaging as other applications on their phone and were subsequently likely to ignore completing their athlete monitoring. While athletes felt that the questions used in the AMS were generally sensitive to changes in their health, some athletes wanted to add their own questions, or remove others, or perhaps contextualise some questions further if they felt they were not specific enough.

Understanding of the Athlete Monitoring System

The majority of athletes indicated that they were confused about how to use the rating scales within the mobile application, and some reported that they did not see how the mobile application could help them in their athletic career. This issue was recognised by the coaches who had tried to address it through individual education sessions. Both athletes

and coaches also commented that the level of coach understanding of AMS use and interpretation varied markedly between coaches.

Table 8. Thematic analysis of pre-intervention interviews

Higher order themes	Lower order themes	Representative meaning unit	Number of sources		Total meaning units
			Athlete (n=8)	Coach (n=3)	
Application of Athlete Monitoring	Develop athlete	[The monitoring] was to teach them [athletes] to be professional. To let them know what it's going to be like when you become a world-class performance athlete. (C03)	0	3	11
	Performance insights	There was a few times that I was just exhausted in myself, and I really wanted to compete, but my coach was like, this is the time where you really need to pull out of this competition and save your energy for the next one, it was the right decision, that [athlete monitoring] evidence helps me make important decisions. (A8)	5	3	32
Attitude towards monitoring	AMS value	So, in terms of helping performance, I don't know if we're there yet, but definitely in terms of flagging up potential injuries or potential, you know problems with the athlete; it's been really good for that. (C03) I think it could [be valuable], I don't think it's being used, like to its full potential yet. (A02)	6	2	9
	Coach approach	So, I'm very performance driven, as is [coach x] but [coach y], is not at all, in terms of monitoring data, evidence, you know he's very technical orientated instead. (C01) I'm happy with the system, and if it's the players data, it's one hundred percent, it's perfect. (C02) One coach looks at the monitoring data, but like, the other doesn't really care that much about it. (A07)	5	3	21
	Engagement / buy-in	I'm old-fashioned, I like to write data out… so yes, we have the app, but I have my files, and so, this gives me, sometimes gives me faster answers. (C02) I don't see like why they should, like they weigh us there, like the weighing stuff shouldn't be on the App. (A01) I know like a lot of our players that have it, they don't really engage in it, and we have players that aren't even in the full-time centre, that fill it in more than our full-timers. (A03)	4	2	23
	Honesty	For the most part, yes [athletes are honest]. Where I struggle with it, or I know that they're not honest, is when the score is exactly the same for twenty-eight days in a row. (C03)	7	3	15

		I'm honest most of the time. If I forget to fill it in, sometimes I just put something in to put something in, but I try to be as honest as I can. (A04)			
	Motivation	I just don't feel like, do you know on your phone you go on your Apps, it's not one that you'd want to go on. It's not interesting. (A05) On the computer you can see the graphs and stuff of your body weight and things like that, but again, I am just looking at it for the fun of it, I suppose. (A02)	7	0	12
	Understand-ing	No, I don't know if they [athletes] see the relevance of the app. (C03) It's not clear, like it says like, give a 1 to 10, but what's 10, what's 1? So, it's a bit hard to, like so I could put in like something 1, when I mean 10. So, I could be not giving them the correct sort of information. (A05)	6	3	20
Communication	Feedback	I've seen a lot of people who collect data, but the athletes never see what happens with that data, so they don't actually feel there's any benefit to them, even though the coaches might well be making decisions based on it, the athletes don't know that. (C01) The feedback we get off one coach is great, but I think our other coaches need to see the data as well, so he knows how my training is actually affecting us. (A03)	8	2	30
	Taking action	I will get an email from them, saying this person reported a low wellness score. And all it does is it, you know it initiates me to create conversation with the person. (C03) If there was a massive change [in scores] from day-to-day, I think they [coaches] would modify training. (A03)	8	3	14
Measure	Adherence	At the moment the uptake for wellness data and stuff around competitions is pretty low, which is kind of expected. (C03) I tried to do it, but then I'd forget and then I'm like oh I'll start again next month, because I'm just like there's no point doing it one in every so often. (A04)	8	2	21
	Logistics	This App is like really simple, it's just like click a button, it's not like you have to write and stuff, so it's like they can't make it any simpler really. (A01)	4	2	10
	Questions	I think [the questions are] pretty solid; like they cover most bases. (A06)	8	0	10

Table 9. Thematic analysis for post-intervention interviews

Higher order themes	Lower order themes	Representative meaning unit	Number of sources		Total mean-ing units
			Athlete (n=7)	Coach (n=3)	
Changes During Intervention Period	Personnel changes	I think the problem we still have, if I'm honest, is it's been coach Y doing it and not coach X, so, not both. So, with both leaving we'll have the possibility to change, and make [athlete monitoring] better…….so, I'm seeing improved [athlete] behaviours, definitely, and more responsibility. (C01) We've lost the head coach, so, you know there's a big period of change…Yeah, so, everything that we've come up with, all the ideas or solutions that we had, are all valid; are all reasonable, and all actually achievable. It's just the climate we were in at that time…made it very difficult for us. (C03)	1	2	12
	Engage-ment/ buy-in changes	My perception is we've made changes; that's what has changed. We've listened to what they've said and tried to change. I don't think there has been much change from them [the athletes]. (C01) Yeah, yeah, the athletes filled it in and used it properly. (C02) I fought really hard to get [them] engaged with it at the beginning, to get them to buy-in and to use it. And I feel like I fatigued in my battle with it to engage them,…..I felt I was fighting a losing battle with them, so, I kind of just let the energy of it slip and actually watched it slowly go into not being used anymore. (C03) I stopped using the App as much as the last time. So, I was using it all the time, and now I've only just started using it again. (A02)	3	3	23
	Unintended Con-sequences	Yes, exactly, so, getting them to be on their phones in the gym to fill in their gym data, I don't know if they're actually doing that of whether they're messaging people at the same time…and if we [removed athletes from sessions] nobody would get individual sessions. (C03) Because the engagement was so low, the person with the highest engagement was like thirty, forty percent. So, I was actually celebrating people not really engaging [with an adherence leader-board], so, I knocked that one on the head. (C03)	0	1	3

Athletes & Coach AMS Perceptions	Athletes & the AMS	There is more an awareness they need to be more professional. So, regardless of whether they've filled in the data or not, they recognise that we're trying to push them to be better athletes. (C03) The problem is not the monitoring system, the players are not enough educated to understand how monitoring system works and how important it is, how monitoring system can support them. There is a gap. (C02) I filled it in every day, all the time, so, I was consistent then. But since I got to a point where nobody else was doing it and they weren't being punished for not doing it, and I wasn't getting any feedback from it, so, I just stopped doing it. (A02) I'm more aware of like the impact that the training is having on me, and through the effort [rated on the AMS] I can see like some days I'm more tired than others. (A04)	7	2	34
	Coaches & the AMS	I think the problem we still have, if I'm honest, is it's been one coach doing it and not the other, so, not both. So, with both [coaches] leaving we'll have the possibility to change that…. I think that's key, if the whole team aren't driving it you're going to have an issue. (C01) I feel like they need someone almost in a full role to be able to continue to press them on [athlete monitoring]…. Because trying to get them to do it in their own time, when they're on their phones all the time, it just doesn't happen. (C03)	4	3	21
Leadership	Manage-ment	I wanted to build a system that got the best out of [Coach X], because that's such a key role….but I think this time I'll just get the [athlete monitoring] system working exactly how I want it to work, and then whoever comes in next will have to fit to that system. (C01) We tried evolution and we tried carrot and stick, but like I said, I'm not a stick kind of guy. But I think we probably needed something a little bit harder to driver it home. (C01) And if my role was purely just performance support, this [athlete monitoring] would be a priority for me; I'd check on a daily basis. Because I'm running the whole programme and doing all the competition schedules at the moment, it's so low down on our list of priorities. (C03) Yeah, it's just that we don't get asked to do it anymore, like we don't get always like kept on, like they're not always like come on do that, nothing like that. They're just far more chilled about it. (A01)	2	2	19
	Athlete Monitoring Direction	The other point is we get Support Services back again in September…. I'd really like to be able to compare and contrast, based on the [athlete monitoring] load. And so, again the athletes will see the value of that. (C01) The [coach manager] is quite keen on just seeing who uses the AMS without us pushing, just to get an idea of who is autonomous about their performance without us having to press them all the time. And answer is pretty obvious for me, it was very few of them, which is a shame. (C03)	0	2	6

7.3.2 Post Intervention Interviews

Changes During the Intervention Period

During the 6-month intervention period some substantial personnel changes occurred within the sport, with two of the coaches announcing that they were due to imminently leave their posts. The head coach left while post-intervention interviews were taking place and the coach leading the AMS intervention left shortly afterwards. These personnel changes significantly impacted the ability to implement the behaviour change intervention and also led to the intervention being de-prioritised (see Table 9). Despite this, the coaches reported that sections of the behaviour change intervention had been implemented (see Table 6 for more details), and athletes indicated that they had noticed this, but were less able to articulate what the changes were (Table 9). One coach indicated with some frustration that the coaches had changed and listened to athlete needs, but that athletes had shown a lot of inertia to change (Table 9). Out of the six behaviour change targets identified in Table 6, two were fully implemented (1 and 6), two were partially implemented (2 and 5) and two not implemented (3 and 4).

Buy-in to the AMS by athletes was identified as important by all staff. Nonetheless, only one of the three coaches felt that they had achieved reasonable athlete engagement with the AMS, with the other two staff members indicating that there was still significant room for improvement. These two coaches indicated that while athletes generally displayed a demonstrable awareness of the requirement of professionalism, this did not translate into change or action (Table 9). Many of the athletes reported that they had poorer adherence to the AMS post intervention in comparison to pre intervention, and this was apparent also from Figure 12. One coach indicated that they had felt increasingly disenfranchised with the AMS, primarily as a result of failing to be able to increase athlete engagement, despite significant attempts to improve the situation.

Some unintended consequences of the behaviour change techniques became apparent in the post-intervention interviews. These included the use of the mobile platform distracting athletes from completing their athlete monitoring, i.e. another mobile application would compete for and win their attention. Some behaviour change targets, like the use of a physical leader board which displayed AMS adherence rates were removed, as they only served to highlight poor adherence (see Table 9). It was also apparent that the coach who led the intervention had become disenfranchised with the AMS. They reported significant

frustration in relation to athlete engagement with the AMS, and felt that the only way to resolve the poor adherence was to employ someone full-time to manage the AMS (see Table 9). Finally, it was clear that the internal changes in staffing contributed to a change in priorities within the sporting organisation, resulting in the behavioural change intervention to increase AMS adherence being deprioritised.

Coaches and Athletes and the AMS

The post-intervention interviews demonstrated that athletes had a range of comprehension of the AMS, from not really appreciating or fully understanding its capabilities, through to using the tool to help them learn more about how they react to training. Therefore, a gap was apparent between the athletes' current understanding of the AMS and how the coaches would ideally like them to perceive the AMS. This was exemplified by one coach stating that the problem lay with the athletes and not the monitoring system. Despite this, there were reports that the athletes' awareness of the AMS and the level of professionalism expected of them was noted to have improved. Pre-intervention differences between the coaches' engagement levels with the AMS were noted; these differences persisted in the post-intervention interviews and became increasingly problematic, as seen in Table 9.

Leadership

Coaches primarily reported taking a positive reinforcement approach to the behaviour change intervention; however, this was reconsidered in light of the poor progress made on improving athletes' adherence to the AMS (Table 9 and Figure 12). A de-prioritisation of the behaviour change intervention was described during the latter stages of the intervention given the personnel changes and subsequent hand-over of work that occurred in the last month of the behaviour change intervention. This can be seen by athletes reporting that there was a reduced emphasis on completing the AMS (Table 9) and the overall drop in adherence rates over time (Figure 12).

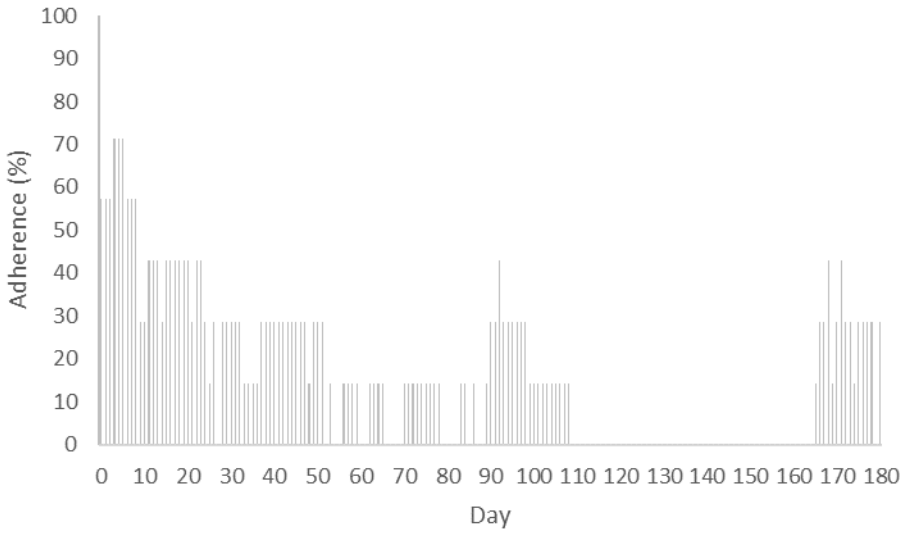

Figure 12. Athlete adherence rates to their athlete monitoring system during the 6-month long (Day 0–180) behaviour change intervention. The gap in adherence between days ~110–160 foreshadowed the personnel changes discussed in the text.

7.4 Discussion

Within the literature, poor engagement of athletes with their AMS has been reported as a significant barrier to successful AMS implementation (Barboza et al., 2017; Saw et al., 2017). This study aimed to examine whether a behaviour change intervention to improve athlete engagement with their AMS could feasibly be implemented in a national team combat sport. A second aim was to examine if the intervention could also improve athlete AMS adherence. During the intervention, significant personnel changes to the coaching team occurred. The behaviour change intervention did not appear to be robust to these changes, with the intervention deprioritised by the coaching team and only partially implemented (see Table 6), with little to no positive change in athlete AMS adherence observed (Figure 12). Therefore, the null hypothesis was accepted and H_1 rejected, with H_2 unable to be fully tested, as discussed in Chapter 7.1.

To maintain a focussed examination of results, this discussion section is split into three main sections that reflect significant experiential content from this study. These sections are: leadership and direction of the AMS, engagement with the AMS, and the use of the behaviour change wheel as an intervention strategy. Each of these sections focusses on some of the consequences and occurrences during the intervention period, the perceptions of the athletes and coaches involved in the study, and the utility of the behaviour change intervention itself.

7.4.1 Leadership and Direction of the Athlete Monitoring System

The different needs of sporting organisations has resulted in inevitable variety in how AMS are planned (Taylor et al., 2012), engaged with by stakeholders (Barboza et al., 2017; Saw et al., 2015b), and subsequently embedded into sporting organisations. An example of how AMS can be customised was observed in this study when the primary aims of the AMS were atypical (Halson, 2014), and reported as "increasing athlete professionalism" (Table 8). Athlete professionalism was explained by the coaches as promoting behaviours expected of their athletes at the world class level, and was felt by the coaching team to be reflected by AMS adherence (Table 8). The coaches reported this aim was selected, as they felt it was an important characteristic that elite developing athletes should demonstrate. Indeed, attributes such as a hard-work ethic, motivation and athlete's understanding of the nature of their sport have been cited as some of the key characteristics that facilitate the careers of junior team athletes (Dohme et al., 2019; MacNamara et al., 2010). Typically, the primary aims for AMS outlined in research have however not included athlete professionalism. Instead, performance optimisation and illness/injury prevention are usually the key objectives (Halson, 2014), but similar to the concept of 'professionalism,' athlete accountability has been cited as an AMS aim elsewhere (Manley & Williams, 2019).

This fundamental difference in athlete monitoring objectives perhaps reflects the junior national team (<21 years) standing of the athletes. As the junior national team athletes are likely still accumulating the behavioural attributes expected of senior national team athletes, the same athlete monitoring aims and objectives reported by senior teams may not necessarily be appropriate (Dohme et al., 2019). Previously, psychological characteristics that have been linked to developing excellence in athletes have included attributes such as commitment and working on weaknesses (MacNamara et al., 2010). Arguably, these are the type of characteristics the coaching team were trying to develop in their athletes by targeting 'professionalism.' Nonetheless, despite the coaching team feeling that the primary role of the AMS was clear, the athletes instead perceived the primary role of AMS as supporting their performance and flagging up potential illness/injury concerns (Table 8). These expectation mismatches were particularly apparent when athletes reported that coach feedback on athlete monitoring was insufficient and did not necessarily help their performance (Table 8). Similar findings relating to athletes receiving insufficient feedback have also been reported in the literature (Barboza et al., 2017). This difference in understanding of the AMS role may have contributed to athletes

failing to adhere to completing their monitoring, as differences in coach/athlete understanding have been shown to negatively affect the coach-athlete relationship (Jowett, 2017).

The coach manager stated a preference for 'bright-side' (i.e. socially desirable) leadership techniques (Cruickshank & Collins, 2015). For example, the sporting organisation was reportedly built around the coaches' strengths (Table 9). However, in the post intervention interviews there was an acknowledgement by the coach manager that a heavier handed approach, using punitive measures such as athlete deselection from teams, might be needed to ensure that athletes and coaches complied with AMS expectations (Table 9). Such 'dark-side' (i.e. socially undesirable) traits of leadership have been proposed to be part of an effective suite of leadership behaviours (Cruickshank & Collins, 2015). Nonetheless, the evidence to support the claim that dark-sided traits form effective leadership techniques is unclear, particularly as it is argued that dark-side traits may have deleterious effects on forming long-term positive working relationships within elite sport (Mills & Boardley, 2017). Nonetheless, the bright-sided leadership approach led to one coach reporting that the poor athlete engagement resulted in them feeling fatigued and frustrated in their efforts to engage the athletes with their AMS. As a result, they reported losing momentum with the intervention (Table 9). Such emotions have previously been found to be contagious within an organisation, and may have further have exacerbated the poor AMS engagement observed (Wagstaff et al., 2012), arguably resulting in athlete comments that the coaches appeared less concerned about AMS adherence in the post-intervention interviews (Table 9).

Coaches and coaching management within the sporting organisation primarily dictated the implementation of the intervention in a 'top-down' approach. Synonymous with a preference for bright-side traits, they also adopted more of an emphasis on 'carrot' than 'stick' to achieve their aims (Table 9). A top-down approach to administering behaviour change has been highlighted as challenging to administer within a complex adaptive system, as it can result in unintended consequences, and failure to adapt to the targets outlined in the behaviour change intervention (Gomersall, 2018). A complex adaptive system has been defined as a network of heterogeneous individuals that act, respond, and adapt to the behaviours of others within the system (Gomersall, 2018). Examples of unintended consequences that occurred within this complex system were: when the use of

mobile platforms for the athlete monitoring became a tool for distraction rather than engagement, as also observed elsewhere (Brooks, 2015). Additionally, the leader board displaying athlete adherence rates to the AMS inadvertently became a celebration of poor rather than good adherence (Table 9). It has been argued that the unintended consequences brought about by change in a complex adaptive system can instead be harnessed to highlight areas where improvement is required and further evolve practice (Gomersall, 2018). Within this case-study, this might point to rethinking measures that coerce or incentivise engagement, particularly if there is a risk that they may not go as planned.

The top-down approach to the behaviour-change intervention also led to a failure to implement all of the targets that were identified in Table 6 when the coaching team experienced personnel changes, and the behaviour change intervention was subsequently de-prioritised (Table 9). Job precariousness and frequent personnel changes are relatively commonplace in elite sport, due in part to performance pressures and short-term staff contracts (Barros et al., 2009; Gilmore et al., 2018). This can lead to projects that aren't directly perceived as being involved in the next medal opportunity (i.e. an AMS) failing to receive attention, a situation that may be exacerbated by simultaneous organisational change (Gilmore et al., 2018). The imminent loss of two coaches led to significant flux within the sporting organisation, with one coach reporting that they employed a 'fire-fighting' approach to maintain the day-to-day needs of their role (Table 9). A casualty of this approach was the prioritisation of the behaviour change intervention, resulting in failure to fully implement it (Table 6 and Table 9). The coach-manager felt, however, that this status of flux presented an opportunity to positively change the staffing structure and make athlete monitoring a key performance indicator for the team (Table 9).

7.4.2 Engagement with the Athlete Monitoring System

Engagement and buy-in of key stakeholders has been highlighted as key to a successful AMS, but simultaneously a potential barrier to use (Barboza et al., 2017; Saw et al., 2015b). The issue of poor engagement of athletes and coaches with AMS has been observed throughout this thesis and in the literature (Akenhead & Nassis, 2016; Saw et al., 2017; Weston, 2018). While most athletes and coaches in this study indicated that they felt the AMS had value for their sport, there were significant problems reported with both athlete and coach engagement with the AMS. Coaches and coaching management primarily perceived the athletes as responsible for poor AMS engagement. In comparison, athletes

reported that not all the coaching team were fully engaged with the AMS, and this contributed to their rationale for poor AMS adherence (Table 9).

Poor athlete buy-in and understanding of the purpose of athlete monitoring is a pervasive issue (Barboza et al., 2017), and was highlighted by the coaches as a key problem to address within the behaviour change intervention. The athlete's ability to understand the AMS and their motivation to engage with it appeared to vary widely within the team, despite athletes noting that the AMS was easy to use and both relevant and useful (Table 8). On an individual level, the varying motivation levels of athletes to engage with the AMS might in part reflect that the AMS is imposed on them. Self-determination theory (Deci & Ryan, 2002) indicates that the imposition of an AMS may lead to a reduction in an athlete's sense of autonomy, which may contribute to feelings of loss of control. This finding is supported by research indicating that athletes can feel disempowered by AMS (Manley & Williams, 2019).

Inter-individually, the impact of athlete-perceived poor communication on the coach-athlete relationship was apparent, with athletes reporting that they received insufficient feedback (Table 8 and Table 9). Similar problems were reported in Chapter 6 and elsewhere (Barboza et al., 2017; Saw et al., 2015b). Some athletes reported that they perceived the AMS to be unnecessary or perceived the questioning to be 'hostile' (Table 8), which was not the stated intention of the coaches (Table 8). This could be explained by previous research indicating electronic monitoring was found to increase the likelihood for individuals to report monitoring practices to have deceptive objectives (Manley & Williams, 2019). These factors, in combination with inter-coach variation in AMS engagement, may further undermine an athlete's desire for competence and relatedness (Deci & Ryan, 2002) and result in amotivated or externally motivated athletes, as arguably seen by some of the athlete comments in Table 8 and Table 9.

In comparison to athlete reported reasons for poor engagement, coaches reported that gaps in athlete motivation, poor understanding of AMS value, and insufficient athlete education were the predisposing factors to poor athlete engagement (Table 8 and Table 9). Similar findings have been published elsewhere (Saw et al., 2015b). It appears from athlete comments in this study (Table 8) that some of the issues the coaching team described may be contributory factors to the poor AMS adherence (Figure 12). However, the coaches level

of buy-in and engagement with the AMS was highlighted by both athletes and coaches (Table 9), and others (Akenhead & Nassis, 2016; Weston, 2018), as a vitally important step in achieving AMS engagement.

Coach buy-in is an antecedent to AMS engagement and thus its success (Saw et al., 2017); however, differing levels of coach buy-in and understanding of the AMS were apparent in this study (Table 9), with athletes reporting that their athlete monitoring feedback was inconsistent between coaches. While insufficient feedback practices have been reported both throughout this thesis and elsewhere (Barboza et al., 2017), differences in feedback practices between coaches and within a coaching team has not been previously reported. While two of the three coaches reported regularly incorporating AMS data into their daily practice, one coach indicated a preference for pen and paper data collection (Table 8). This resulted in the coach displaying limited subsequent engagement with the online athlete monitoring data. Nevertheless, the same coach reported in interview that they were happy with the AMS and that the data it gathered was useful to them (Table 8). These contradictions appear to be either the result of cognitive dissonance (Harmon-Jones & Mills, 2019) or interview response bias (Silverman, 2010).

The variability between how the coaches employed the AMS appeared to cause friction and stress within the coaching team, with coaches reporting that one of their coaching team had not bought-into the process. Conflict within the organisation has been previously reported as a significant source of stress for elite coaches (Olusoga et al., 2009), along with coach-coach tension (Thelwell et al., 2008). This friction may also have contributed to some of the negative perceptions athletes had of the AMS, because inconsistency between coaching styles has previously been shown to be a stressor that can be detrimental to the coach-athlete relationship (Woodman & Hardy, 2001). Therefore, consistency and 'quality assurance' between coaching approaches to athlete monitoring should be employed by coaching management to ensure the quality of the coach-athlete relationship is supported, and not antagonised (Manley & Williams, 2019), by the introduction of an AMS.

Previously, research has indicated that by playing to both the coach's strengths and existing interests, practitioners can help build momentum to achieve buy-in for their own goals (Gilmore et al., 2018). By sticking rigidly to the behaviour change targets identified by the behaviour change wheel (Michie et al., 2014) the ability to capitalise on existing 'wins' to

achieve coach buy-in, and also leverage the coach-athlete relationship to gain athlete buy-in, was perhaps diminished (Jowett, 2017). Accordingly, perhaps interventions which played to coaching strengths, for example technical analysis, should have been prioritised to ensure technical video analysis was embedded into the AMS and integrated into athlete case conference meetings. This would have played to the strengths of the coach who was least engaged with the AMS, whilst simultaneously creating accountability to their peers in meetings. The findings from the pre and post intervention interviews in Table 8 and Table 9 also indicate the influence of coach engagement with the AMS and the coach-athlete relationship on driving athlete AMS engagement.

7.4.3 Is the Behaviour Change Wheel the correct tool for the job?

The behaviour change wheel provides a practical and evidence-based toolkit to support practitioners implementing a behaviour change intervention (Michie et al., 2014). In this study, the majority of the target behaviours identified by the behaviour change wheel met the APEASE criteria (Table 7), and coaches agreed that the target behaviours were practical and reasonable to address (Table 9), with some felt to be slightly easier to implement than others. As the author of this thesis was not embedded in the sporting organisation, it was agreed that the coaching team were in a better position to implement the intervention, given the social capital they held within the team. Previously, social capital has been shown to be important in influencing the achievement of goals (Wagstaff et al., 2012).

The use of the behaviour change wheel also allowed application of behaviour change theory to the development of a range of feasible behaviour change interventions within elite sport. To date, the behaviour change wheel has only been used for nutritional intervention in elite sport (Costello et al., 2018); therefore, the use of the behaviour change wheel within the context of increasing adherence to AMS was novel in this context. However, personnel changes in the sporting organisation during the intervention period led to a deprioritisation of the behaviour change intervention. This deprioritisation occurred despite the established feasibility and scientific underpinnings of the proposed intervention (Table 7). Furthermore, it became apparent during the course of the intervention that some of the identified target behaviours (Table 6) became unsuitable to pursue or resulted in unintended consequences. For example, the removal of 1:1 training sessions as a consequence for poor AMS adherence would have reduced athletes training volume. Additionally, promoting the use of mobile devices to complete the AMS led to the devices becoming a distraction, with the coaches becoming suspicious that athletes were using the

internet and other mobile applications rather than completing their monitoring (Table 9). Therefore, it was not possible to fully implement the full range of target behaviours identified by the behaviour change wheel (see Table 6).

To date, despite significant scientific evidence underpinning the behaviour change wheel, it remains a predominantly theoretical construct (Michie et al., 2014). For example, the majority of studies to have utilised the behaviour change wheel have either produced an intervention framework that has yet to be implemented or evaluated (Chiang et al., 2018; Munir et al., 2018), or have systematically reviewed existing interventions (M. Richardson et al., 2019). There are few researchers, with some exceptions (Costello et al., 2017, 2018), that have applied the behaviour change wheel and subsequently published their findings. Therefore, while the behaviour change wheel has strong theoretical underpinnings and provides a clear and systematic approach to devising a behaviour change intervention (Michie et al., 2014), the subsequent ability of the intervention to be implemented and effective is unclear.

One criticism levelled at the behaviour change wheel is that it is based on social cognitive theory (Munro, 2016). Social cognitive theory is underpinned by the concept of reciprocal determinism and a causal chain, i.e. a linear deterministic system (Bandura, 1986; Gomersall, 2018). Subsequently, when behaviour change interventions are viewed through a social cognitive lens, it is assumed that the better planned and researched the inputs, in this example the target behaviours, the larger the outputs, i.e. the changes in behaviour. However, this mechanistic approach fails to take into account the impact of non-linear influences on thought and action (Resnicow & Vaughan, 2006). Non-linear processes do not assume a smooth relation between cause and effect and the scale of the intervention does necessarily lead to a proportionate change in the outcome variable. Examples of non-linear changes can be seen in other fields where relapses in substance abuse occurs with minor apparent changes in risk factors (Hayes et al., 2007).

The assumption of linearity underpinning the behaviour change wheel is important, as human behaviour and behaviour change within the context of the elite sport system are not necessarily linear. Instead, sporting organisations and the behaviour within them have the features of what is known as a complex adaptive system where non-linear responses in behaviour might occur as a result of a behaviour change intervention. In this study, despite

coaches indicating that athletes demonstrated improvements in attitudes and knowledge of athlete monitoring, athlete reported behaviours and athlete monitoring adherence did not change (Table 9 and Figure 12). Therefore, despite implementation of elements of the behaviour change intervention (Table 6), no clear relations were observed between the intervention and the improved athlete adherence to their AMS. This finding contradicts the social cognitive paradigm assumptions implicit in the behaviour change wheel, i.e. that attitudes and beliefs can be influenced by a behaviour change intervention (input), which then has a linear relationship with behaviour (output) (Michie et al., 2014). Instead, the lack of change observed, and the failure to fully implement the behaviour change intervention were arguably a result of the behaviour change intervention being implemented in a complex adaptive system (Gomersall, 2018). This could be characterised by the athletes adapting to the changing environment (personnel changes), non-linearity of response (lack of expected behaviour change) and the distributed control of behaviour (relationship between athletes, coaches and other individuals/groups) (Resnicow & Vaughan, 2006).

While the behaviour change wheel does not claim to be a panacea for bringing about behaviour change (Michie et al., 2014), it's inherent assumption of stability within the environment to which it is applied raises questions about its ability to be both successfully implemented and adapted to the dynamically changing demands of an elite sport environment. This assumption was tested in this study when personnel changes led to incomplete implementation of the behaviour change intervention (Table 6). As a result, the alternative hypothesis (H_1)that 75% or more of the behaviour change targets would be implemented was rejected, and the null hypothesis accepted, as only two behaviour targets were fully implemented (Table 6). Accordingly, H_2 was not tested, in line with the methodology set out in Chapter 7.1. As behaviour change is linked to context (Gomersall, 2018), unless a behaviour change intervention can be adapted to the dynamically changing nature of the elite sport environment, it risks failure. Instead, it might be prudent to utilise the systematic approach of the behaviour change wheel to identify suitable behaviour targets but combine this approach with other research findings. For example, some researchers have indicated that within a complex system, intervention success is dictated by the effectiveness of interactions at different levels within the organisation (Keshavarz et al., 2010). In this thesis, examples of key interactions are likely to include the coach-athlete dyad and how they relate to and use the AMS data. Findings from this thesis would indicate other key interactions to be: establishing feedback loops from the AMS data obtained to

the athlete, and the flow of information between the sporting organisation and other agencies, such as academic researchers (Keshavarz et al., 2010). Identifying these key interactions and focussing on improving them may allow an approach that is able to adapt to the changing demands of an elite sport environment. Based upon the findings from this thesis, it is clear that the coach-athlete relationship and the coaches' engagement with the AMS are key factors to consider when trying to improve athlete engagement with an AMS.

7.5 Conclusion

Through use of the behaviour change wheel (Michie et al., 2014), a feasible and practical behaviour change intervention was constructed in combination with the coaching team for deployment in the sporting organisation. Due to personnel changes that occurred during the intervention period, not all the identified behaviour targets were able to be implemented, nor could the behaviour change intervention be easily adapted to changes occurring within the sporting organisation. Thus, there was no improvement in adherence to the AMS during the intervention period (Figure 12). Nonetheless, while coaches reported that there was no significant change in athlete adherence in relation to the AMS, they reported an improvement in athlete awareness of athlete monitoring (Table 9). Overall, this study found that while the behaviour change wheel allowed practical behaviour change targets to be discerned, the time-consuming nature of its approach prevented it from being easily modified. With a complex systems lens, the linear-deterministic nature of the behaviour change wheel risks over-simplifying the complexity of the situation it tried to address. To provide a more agile approach to implementing behaviour change interventions, it is recommended that behaviour change targets are instead focussed on key interactions within the sporting organisation. These should include the coach/athlete dyad and its interrelation with AMS data, and feedback of AMS data between the practitioner, coach and athlete.

7.6 Practical Applications

- The behaviour change wheel can provide practitioners with a systematic and rigorous method to identify suitable behaviour change targets.
- There are assumptions inherent in the behaviour change wheel, such as the notion that a linear relationship exists between behaviour targets implemented and the behaviour change outcome. This over-simplifies the complex adaptive system nature of the elite sport environment.

- An expectation should be set that coaches as well as athletes should engage with the AMS. Significant differences between coaching approaches risks disenfranchising both athletes and other members of the sporting organisation.

8.0 Chapter Eight - General Discussion

8.1 General Summary and Discussion

Each experimental chapter of this thesis contains a discussion section. To avoid replication, this general discussion chapter therefore includes: a summary of findings, a concise discussion highlighting key points from each chapter, and a brief philosophical examination of the role of athlete monitoring in elite sport resulting from some of the issues raised in this thesis.

In summary, this thesis took the following path: Chapter 2 identified that there were gaps in our understanding of athlete monitoring practices in elite sport in the United Kingdom. These gaps, including the extent and nature of the use of customised metrics, were explored in Chapter 4. The value practitioners placed in their AMS in respect of these issues was then examined further in Chapter 5. As engagement of athletes with the AMS was highlighted as a significant barrier to implementing an effective AMS in Chapter 5, a cohort of elite athletes were interviewed as part of Chapter 6 to ascertain what these issues might be. Finally, the practicality of implementing a behaviour change intervention to address some of the engagement issues identified in the previous chapters was explored in Chapter 7 (see Figure 2). Overall, this thesis has critically reviewed athlete monitoring practices in elite sport in the United Kingdom. It has also focussed on the poor reported engagement with AMS and if it is practical to improve athlete engagement from a case study within a sporting organisation.

The following sections of this discussion presents several questions to aid summary of the findings from this thesis, with a focus on the experimental Chapters 4–7. The aim of this discussion is to summarise and contextualise the importance of these findings for applied practice. Firstly, the discussion section posits that the scientific integrity of athlete monitoring is diminished by the proliferation of custom measures with poor methodological rigour. It is argued that the findings from this thesis, such as athletes receiving insufficient feedback, likely impacts the efficacy and thus practical utility of the AMS. Secondly, this discussion section contends that while a departure from research-advocated best practice may negatively impact scientific integrity of the AMS, paradoxically it may not necessarily negatively influence subsequent decisions made in relation to athlete training programmes. Finally, the possibility of using a behaviour change intervention to positively impact some of the issues surrounding poor stakeholder buy-in is discussed.

These questions provide a framework through which to explore the findings of this thesis in the context of applied practice in elite sport.

8.2 Summary of Key Findings and their Implications

8.2.1 Does the gap identified between best practice and applied practice matter?

The literature review in Chapter 2 indicated that there was a paucity of data on what the practices and perceptions of AMS were in elite sport in the United Kingdom. The data that does exist, however, pointed towards applied practice deviating from what researchers advocate (Saw et al., 2017; Taylor et al., 2012). Chapter 4 was able to give a comprehensive insight into the landscape of athlete monitoring in elite sport in the United Kingdom, therefore addressing the lack of data in this area. Further, it outlined where some discrepancies occurred between what researchers advocate, and what was happening in applied practice. Some of the key issues highlighted in Chapter 4 included the customisation of athlete monitoring metrics, often resulting in a lack of scientific rigour, unsuitable question and response design within the AMS, and failure to follow best practice when analysing AMS data. These issues are discussed in more detail below.

The customisation of athlete monitoring metrics has been reportedly driven by a lack of sports specificity in existing published tools and the often lengthy nature of validated tools causing questionnaire fatigue (H. McGuigan et al., 2020; Taylor et al., 2012). Athlete self-report measures are a type of athlete monitoring metric; they have been a specific focus of this thesis as they are relatively easy to customise (Taylor et al., 2012). In addition, athlete self-report measures are one of the most frequently utilised measures across sporting organisations, as reported in Chapter 4 (see Figure 5 and Table 2). The inherent variability caused by the customisation of monitoring measures therefore presents a significant risk of applied practice deviating from what is advocated by researchers.

Given the widespread use and customisation of athlete monitoring metrics, it was arguably unsurprising that 24% of practitioners reported that there was no clear scientific underpinning to their measures (Chapter 5). Additionally, practitioners reported that they had difficulties identifying meaningful change in AMS data, with 24% of practitioners indicating that they had no defined method to assess meaningful change (see Chapter 4). Where customised metrics are not scientifically validated or evidenced, they can present a significant hurdle to correctly identifying meaningful change within the data (Saw et al., 2017; Windt et al., 2018). This is because, without scientific validation or underpinning

evidence, it is unclear whether athlete monitoring metrics actually measure what they purport to measure (Impellizzeri & Marcora, 2009). A failure to utilise measures that properly reflect athlete training status therefore risks undesirable consequences, such as athlete maladaptation and/or underperformance (Bourdon et al., 2017).

A second issue highlighted at the outset of this section was the use of unsuitable custom question and response design within an AMS. Chapter 4 found that that both the customised athlete self-report questions and response scales varied considerably between elite sports (see Figure 5). Additionally, these metrics frequently did not adhere to best practice scientific recommendations. For example, in Chapter 4 there was evidence of Likert response scales being longer than recommended (Lozano et al., 2008; Saw et al., 2017). Some practitioners were also unclear on why their response scale length had been selected, indicating a lack of awareness of how to construct custom measures or what indeed is best practice in this regard.

Other methods which did not adhere to best practice recommendations highlighted at the outset of this chapter included the use of inappropriate data analysis methods. This has included the use of acute to chronic workload ratio to analyse AMS data, a method that has received substantial recent critique (Impellizzeri et al., 2020; Lolli et al., 2019a). In addition, practitioners reportedly used raw scores (56%) and percentages (16%) to feed back AMS data, and these methods would arguably benefit from further development or refinement.

The findings from Chapter 4 identified numerous gaps between applied practice and best practice. This could be detrimental to the overall scientific rigour of AMS in elite sport and the subsequent ability of practitioners to ascertain meaningful change within their AMS data. It is therefore unsurprising that only 52% (see Chapter 5) of respondents reported confidence in the sensitivity of their athlete self-report measures. Further, a trend was observed between practitioners having confidence in the sensitivity of their athlete self-report measures, and the reported presence of scientific evidence underpinning their metrics ($r_S = 0.398$, $p = 0.049$). Limited confidence in the efficacy of AMS has been reported elsewhere (Akenhead & Nassis, 2016), but was thought to result from an inability to measure athletes during competition. In comparison, this study found that the main reasons for poor practitioner confidence in the sensitivity of their athlete self-report measures was the perception of untruthful athlete reporting practices, and difficulties identifying meaningful change within the data. Of note is that respondents in this thesis did

not directly specify poor scientific rigour or validity as a primary reason for their lack of confidence in their AMS. Arguably however, the issue of uncertain measure validity is inherently linked to the subsequent difficulty respondents had identifying meaningful change within their data, and should therefore be addressed where customised measures are employed (Kyprianou et al., 2019; Windt et al., 2018).

The variable confidence practitioners reported in their AMS in Chapter 5 is likely undermined further by 58% indicating that they worked with internationally successful athletes that did not complete their prescribed athlete monitoring. Left unaddressed this may send out a message within the sport that compliance with an AMS is not a requisite for sporting success. Additionally, practitioners were split 50:50 on whether athletic performance would be compromised if there was no AMS within their sporting organisation. Overall, these findings show that some AMS employed in elite sport in the United Kingdom lack scientific rigour, and arguably as a result, some staff members do not have full confidence in the sensitivity of their AMS metrics, which will likely negatively impact their perceptions of AMS efficacy.

This discussion section has so far explored the findings from Chapters 4 and 5, and how these chapters have highlighted gaps between applied practice and best practice from the literature. It is however important to extend these arguments to consider what, if any, additional problems these gaps may cause for the elite sport practitioner. Chapter 4 reported that sports science practitioners were primarily responsible for the daily administration and management of the AMS. Arguably, these practitioners (primarily physiologists and strength and conditioning coaches) have positivist research philosophies. This likely results from their sports science training and their tendencies for quantitative research paradigms and objective measurement techniques (Vaughan et al., 2019).

As discussed above, the practicalities of the elite sport environment can necessitate the use of customised measurement tools, typically for reasons pertaining to sports specificity and brevity (Taylor et al., 2012). Practitioners therefore face a twofold challenge when they are required to adapt athlete monitoring practices to the needs of the sporting organisation: a challenge to their underlying research philosophies (Ryall, 2019; Vaughan et al., 2019) and the potential of inviting poor scientific rigour through measure customisation (Chapters 4 and 5). Some of the issues raised by the latter are discussed above, but the former issue risks fuelling a reductionist approach to monitoring (Ryall, 2019; Vaughan et al., 2019). Here, practitioners' continued attempts to understand training status via athlete

monitoring may result in the collection of voluminous athlete monitoring metrics, which may have questionable provenance or validity (Duignan et al., 2019a; Vaughan et al., 2019; Weston, 2018).

Sporting organisations and their personnel should therefore be cognisant of the gap that exists between their applied practice and best practice, as outlined in Chapters 4 and 5. This difference matters, because the poor scientific rigour underlying athlete monitoring metrics identified in this thesis increases the chances of failing to identify athlete maladaptation (Saw et al., 2017; Windt et al., 2018). Further, the lack of confidence uncertain measure validity engenders may inadvertently result in practitioners pushing a policy of 'ever-greater' athlete monitoring. Unchecked, the overuse of metrics could cultivate an unintentional culture of hostile athlete surveillance. Some athletes in Chapter 6 felt that their athlete monitoring was used punitively, and the creation of a hostile environment via athlete monitoring, inadvertent or otherwise, has been discussed (Manley & Williams, 2019). These issues will likely be magnified if the rationale for monitoring athletes, i.e. improving performance and reducing illness/injuries, is not met (Chapter 4). Or, if the data from the AMS is perceived by athletes to be used as a stick for removing them from training/competition, or in making funding decisions (Chapters 6 and 7). Findings from this thesis demonstrated that some practitioners have not taken a best practice approach in the construction or analysis of their AMS data. Therefore, practical guidelines that extend existing work (Saw et al., 2017), whilst also providing a novel contribution to the literature were provided in Chapter 10 and Figure 13.

8.2.2 What is the impact of athlete monitoring data in elite sport?

Athlete monitoring systems are only likely to be effective if their aim of preventing illness/injury and optimising performance is met, as outlined in Chapter 4, and in the literature (Halson, 2014). Based on findings from this thesis, key facets of an effective AMS are: metrics should be underpinned by scientific evidence, data collection should be acceptable to end-users, meaningful change within data should be able to be discerned, and the data should be subsequently utilised to inform training programme design (Bourdon et al., 2017). The first section of this discussion argued that the gap between best practice and applied practice has brought into question the efficacy of AMS. This was primarily evidenced by the lack of scientific rigour reported in Chapters 4 and 5, alongside the lack of confidence some practitioners reported in the sensitivity of their AMS. This section contends that despite the aspirations of sports scientists (Gabbet et al., 2017), findings from this thesis indicate that AMS may not necessarily play a significant role in

informing training programme design. Informing training programme design, via coaching decisions, should be a key outcome variable for any AMS (Halson, 2014). This thesis found that the primary barriers preventing AMS data informing training programme design included: difficulties in meeting the AMS aims, poor AMS engagement from coaches and athletes, and insufficient feedback given to athletes. These issues are therefore discussed in more detail below.

When using an AMS, it is important to ensure that it has aims which are agreed by all stakeholders (Saw et al., 2017). In this thesis, the majority of respondents reported their AMS aims either supported the improvement of performance, or managed injury and illness risk (Chapter 4). This is consistent with findings in the literature (Halson, 2014). However, a novel use of athlete monitoring as a method to increase athlete professionalism, as measured by athlete AMS adherence, was also reported by the coaching team in Chapter 7. At a national team level (Chapter 6), agreement was therefore observed between the athlete's perception of AMS aims, and those cited in the literature (Saw et al., 2015b). Nonetheless, these aims were not always felt to be met by the athletes involved.

The agreement between athletes and coaches on AMS aims was however diminished at junior national team level. It was apparent that junior national team athletes still felt the AMS was there to support performance, or prevent injury, rather than to elicit 'athlete professionalism' (Chapter 7). These discrepancies in the perceptions of AMS aims may reflect the differing developmental needs and characteristics required of junior national team athletes, in comparison to their senior team counterparts (Dohme et al., 2019; MacNamara et al., 2010). However, it may also reflect differences between the role of an AMS as perceived by the coach, versus a practitioner or athlete. The confusion in relation to the role and aims of an AMS was underscored in Chapter 4, with 12% of practitioners reporting an insufficient rationale for AMS use, with one practitioner commenting that mixed messages coming from within the sporting organisation elicited this confusion.

Therefore, there appears to be a fundamental need to better align expectations and rationales for AMS use between stakeholders and to ensure AMS aims are attainable. Previous studies have investigated the AMS requirements of national team coaches. These studies have found that coaches primarily used AMS to support injury reduction and, amongst other prerequisites, the coaches wanted the measures to be sports-specific and valid (Roos et al., 2013; Starling & Lambert, 2018). In practice, it is apparent from results of

this thesis that some aspects of AMS do not yet meet practitioner needs, thus engendering a lack of confidence in the AMS. Therefore, by extension coaching requirements (Starling & Lambert, 2018) are arguably also unlikely to be met.

If the coach deems the AMS does not meet their requirements, this may partly explain their reported failure to modify training when changes were observed in AMS data (Chapter 5). Only 44% of practitioners (Chapter 5) and 44% of athletes (Chapter 6) agreed that remedial action was taken by coaches where meaningful changes in AMS data were observed. Arguably, not all meaningful changes in athlete monitoring data require action to be taken, as changes are context specific (Bourdon et al., 2017). However, less than half of respondents reported that action was taken. This finding indicates that AMS data does not necessarily influence coaching decisions to the degree to which it is argued it perhaps could, or should (Gabbet et al., 2017). A trend was also observed in Chapter 5 between the perception of coaches taking action when meaningful change was observed in AMS data, and practitioners reporting that their AMS metrics had a scientific underpinning (r_S = 0.490, p = 0.013). It is therefore advisable that practitioners ensure that robust scientific evidence underpins their athlete monitoring system.

Despite coaches rating AMS as important (Starling & Lambert, 2018), some research has shown that the contribution AMS data makes to informing training programme design is currently minimal (Crowcroft et al., 2020b; Pope et al., 2018). Instead, coaches were primarily found to rely on subjective indicators of training status alongside performance metrics to inform their decision-making and training programme design. Therefore, it appears that the contribution athlete monitoring data makes to coaches' decision-making processes has yet to be optimised, or fully understood. This is an important observation, as addressing the AMS shortcomings discussed in this thesis could help better inform and support coaches in their training programme planning.

At the start of this section, the findings from this thesis indicated that there were three significant issues that may negatively impact the utility of AMS data. The second and third issues, achieving stakeholder engagement with AMS and athletes receiving insufficient feedback are addressed below. Buy-in of stakeholders to AMS was found, in this thesis, to be a significant issue (Chapter 5), and elsewhere (Fullagar et al., 2019; Saw et al., 2015b). Chapter 5 highlighted that coaches were felt to give the least support to practitioners using an AMS (Figure 9), with only 44% of practitioners feeling fully supported by their coaching team. In comparison, 74% of practitioners felt fully supported by their sports science

managers. Further, a third (33%) of practitioners felt that athletes rarely, or only occasionally, completed their athlete monitoring. These findings underscore buy-in as a key barrier to AMS use in the elite sport environment. The reasons for the poor athlete AMS engagement raised in Chapter 5 were however unclear. Therefore, Chapter 6 sought to clarify this through seeking athlete opinions on their AMS. The athletes interviewed reported that their reasons for non-completion of athlete monitoring primarily related to receiving insufficient feedback. In addition, some athletes felt that their completed data would either be ignored or used against them to make decisions relating to their training programme with which they disagreed. This finding is supported by similar results in a different cohort of athletes in Chapter 7 and in the literature (Barboza et al., 2017; Manley & Williams, 2019).

The issue of athletes receiving insufficient feedback was raised by 44% of practitioners in Chapter 4, and by athletes in Chapters 6 and 7. Further, athletes in Chapters 6 and 7 indicated that they received little or no athlete monitoring feedback, and many were unclear whether the feedback positively impacted their performance (Figure 10). Beyond the use of GPS specific information in football (Nosek et al., 2020), there appear to be few guidelines or information pertaining to best practice delivery of AMS feedback in elite sport. The high-level guidance that does exist has deemed AMS feedback necessary (Saw et al., 2017). It has also stated that automated feedback 'dashboards' in an AMS may offset the feedback workload requirements for practitioners. Findings from this thesis, however, indicate that feedback integrated into AMS received little attention from either the athlete (Chapter 6) or the practitioner (Chapter 4). This therefore questions the utility of AMS technology for this purpose.

Overall there appears to be a paucity of AMS feedback guidance in elite sport. There are no clear recommendations for how to present information, nor for the frequency with which to present it. This is unsurprising given the individual nuances and needs of each sporting organisation. This complicates the determination of 'best practice' advice in the feedback of athlete monitoring data. However, this thesis has reported that 'sufficient' feedback to be significantly related to improved adherence levels ($r_S = 0.675$, $p = <0.001$). As athletes placed a high value of receiving feedback from their AMS, this is an area which should be explored in more detail.

In summary, it appears that poor stakeholder engagement, insufficient athlete feedback, and unclear AMS aims combine to reduce the potential impact of AMS data on training

programme design. Therefore, while section 8.2.1 identified that there are significant gaps between AMS research and applied practice, arguably their negative impact is negated by the subsequent poor engagement of athletes and coaches with the AMS. This argument is supported by Crowcroft et al. (2020) and Pope et al. (2018).

8.2.3 How can we improve engagement with athlete monitoring in elite sport?

The final section of this general discussion examines the recurring theme of poor stakeholder AMS engagement. Engagement or buy-in of stakeholders, specifically athletes, coaches and practitioners, is central to the success of an AMS (Bourdon et al., 2017). Where poor engagement with an AMS has been identified (Barboza et al., 2017), the efforts to attain engagement within sporting organisations has been unsystematic and fragmented. Researchers have generally offered pertinent, but piecemeal, advice for solutions, such as improving athlete feedback (Barboza et al., 2017), or providing athlete education to increase adherence (McCall et al., 2016).

Previously, there have been calls for a multi-factorial/multi-level approach to addressing barriers to AMS implementation, such as poor stakeholder engagement (Saw et al., 2015b). While a multi-level approach may be desirable, it may not be practical in the context of the finite time and resources available to sporting organisations. Accordingly, targeted approaches to enhance engagement with AMS, i.e. tailored behaviour change interventions, were explored in Chapter 7 of this thesis. It was argued that this approach reduced the resource burden associated with a broad multi-level approach, while the theory-driven underpinning of a behaviour change intervention increased the chances of improving AMS engagement (Michie et al., 2014).

Therefore, Chapter 7 examined the practicality of implementing a behaviour change intervention to improve athletes' adherence to their AMS. Successful implementation of behaviour change interventions in elite sport have been demonstrated previously (Costello et al., 2018); therefore, the concept of utilising a formalised intervention to modify behaviour appeared feasible. Behaviour change interventions provide a systematic and well evidenced method to positively impact behaviour (Michie & Johnston, 2012). The behaviour change wheel (Michie et al., 2014) also has the benefit of a clear framework to aid practitioners' planned behaviour change interventions. Therefore, with use of the behaviour change wheel (Michie et al., 2014), a series of behaviour change targets to improve athlete adherence were identified in Chapter 7. These targets were drawn from

information provided as a result of interviews with the athletes and coaches, and in discussion with the coaching team during an intervention workshop (see Table 6).

In Chapter 7, two primary research aims were identified: the first was to assess the practicality of utilising the behaviour change wheel in the elite sport setting, and the second, the ability of the intervention to increase athlete AMS adherence. In relation to the former point, the rigorous and systematic process the behaviour change wheel utilised to identify mechanisms for behaviour change was argued to be a strength of the tool. This allowed a feasible and practical intervention to be constructed that was able to be tailored to the sporting organisation's needs. However, the time-consuming nature of completing the behaviour change wheel framework could deter sporting organisations from its use. The length of the behaviour change wheel may also make it less adaptable to any changes that occur within the sporting organisation, e.g. personnel changes. Therefore, while the behaviour change wheel appears to have potential utility in the elite sport environment, its implementation was hindered in this thesis by personnel changes. These personnel changes led to the behaviour change intervention being de-prioritised; and the coaching team instead focussed on maintaining the day-to-day functions of the organisation.

Other difficulties encountered when implementing the behaviour change wheel included its assumption of a linear relationship between the behaviour change targets implemented and the behaviour change outcome (Gomersall, 2018; Michie et al., 2014; Resnicow & Vaughan, 2006). This assumption appeared to over-simplify the complexity of both interactions within the sporting organisation and the differing perceptions stakeholders held of the AMS. For example, some athletes and coaches were more engaged with the AMS than others (Table 8). Therefore, there was no 'one-size fits all' approach for encouraging engagement with the AMS, and no apparent uniform progression towards improved AMS adherence. In addition, it has been argued that the 'top-down' approach the behaviour change wheel employs may result in unintended consequences (Gomersall, 2018). Examples of this were observed in Chapter 7, including the use of the leader-board, originally meant to celebrate good athlete AMS adherence, unintentionally celebrating poor adherence.

Therefore, the behaviour change wheel (Michie et al., 2014) provides an evidence-based and systematic approach to assessing and changing behaviours. However, its lack of adaptability to changes within the environment meant it was unable to successfully bring about behaviour change (Chapter 7). Given the constant change that occurs in the elite

sport environment (Barros et al., 2009; Gilmore et al., 2018), this is a considerable threat to the efficacy of the behaviour change wheel. An alternative approach for practitioners would instead be to focus their use of behaviour change interventions on the key interactions that may improve AMS engagement, as seen elsewhere (Keshavarz et al., 2010). For example, recurring themes in this thesis were the effectiveness of the coach-athlete-AMS interactions, and the feedback loop to the athlete. Therefore, focussing the use of a behaviour change intervention on these identified interactions may help reduce the burden of completing a lengthy intervention assessment, and provide a more agile intervention framework. This approach would however need to be balanced with the potential omission of behaviour targets beyond the feedback loop, and coach-athlete-AMS interactions.

Overall, this thesis presents a picture of sub-optimal functioning of AMS within elite sport in the United Kingdom and provides some insight into why these issues occur. Several key problems have been highlighted, including: examples of poor scientific rigour of monitoring metrics, practitioners lacking confidence in the sensitivity of their athlete self-report measures, ineffective feedback processes, and poor stakeholder engagement. This rich insight into AMS perceptions and practices has enabled guidance to be produced (Chapter 10) to support practitioners to address some of the common issues highlighted in this thesis, thus extending existing work in this area (Saw et al., 2017), and providing a novel contribution to research. Finally, as formal behaviour change interventions have not previously been used in relation to AMS, this thesis was able to provide insight and commentary on the utility of such tools to support the common issue of poor AMS engagement in elite sport.

8.3 Athlete Monitoring Philosophy

Athlete monitoring has been proposed as a tool to help coaches and scientists balance the high training loads and stressors to which athletes are exposed against their readiness to train or compete (Bompa, 1999; M. R. McGuigan, 2017). This thesis, however, has highlighted a lack of clarity about whether AMS in elite sport can meet these aims. There are significant issues with athlete monitoring, such as the scientific underpinning of the athlete monitoring measures employed, the method of data analysis used, lack of feedback given to athletes, confidence of practitioners in their AMS, and poor buy-in from key stakeholders such as athletes and coaches. This thesis has therefore supported some existing findings underlining differences in research and practice in this area (Coyne et al.,

2018; Taylor et al., 2012), while also revealing the extent of concerns pertaining to athlete monitoring in elite sport in the United Kingdom.

In light of these findings, it seems timely to question whether it is aspirational of sports scientists to truly mitigate against illness and injury and optimise performance with athlete monitoring. If, as this thesis indicates, these aims cannot yet fully be met, what is athlete monitoring therefore achieving? Ethically, should we be concerned that data continues to be collected whereby the aims and objectives of athlete monitoring are not, and potentially cannot, be met? Or is it in our duty of care to the athlete to continue to collect such data? These are thorny and uncomfortable questions, but failing to ask them is a failure to adhere to the principles of scientific inquiry (Kuhn, 1970).

It is therefore necessary to carry out a more philosophical examination of the conundrum athlete monitoring is trying to solve, i.e. the inherent uncertainty surrounding athletic performance and any future illness/injury. The human desire for certainty is implicit in Maslow's hierarchy of needs, and is associated with safety, security of knowledge, and understanding (Maslow, 1943). In light of this intrinsic drive for certainty, sports scientists should clarify the aims of athlete monitoring within their sporting organisation, as outlined in this thesis (Chapters 7 and 9 and Figure 13). They must also delineate the difference between risk, which refers to the possibility of alternative outcomes whose probabilities can be measured, or uncertainty, which refers to alternative outcomes where the probabilities cannot be measured (Knight, 1921).

The incidence of injury and illness and nature of excellent athletic performances are multi-factorial (Bourdon et al., 2017; Drew & Finch, 2016; Roe et al., 2017). While it may be possible to monitor and assess some, or even many, factors influencing performance/health (C. M. Jones et al., 2017), it is currently unlikely that all relevant factors can be measured or known. Therefore, what can be measured may help build confidence in our athlete monitoring practices and understanding of the athlete. However, the ability to accurately predict or mitigate injury/illness or improve performance with athlete monitoring is still associated with uncertainty (Knight, 1921). This uncertainty should be communicated with all stakeholders involved in the athlete monitoring process, to help set reasonable expectations of athlete monitoring. For example, coaches need to make binary decisions in relation to training, i.e. training/no training. However, an AMS does not necessarily provide definitive answers; AMS are, therefore, imperfect. Staff within a sporting organisation should be transparent in relation to the capability and uncertainties

surrounding AMS data, particularly where a coach decides that an athlete should continue training, but this is contraindicated by their monitoring data. When such instances are contextualised to the athlete (and practitioner, as necessary), and the uncertainty surrounding decisions discussed, stakeholders' disenfranchisement with athlete monitoring can be, arguably, avoided.

The uncertainty surrounding athlete monitoring data does not divorce practitioners, particularly health care practitioners, from their duty of care responsibilities (J. S. Thornton, 2020); nor should it dissuade practitioners in the pursuit of responsible athlete monitoring practices (Saw et al., 2017). However, practitioners should be aware of their inherent desire for certainty alongside their predominantly reductionist paradigms. They should ensure this doesn't result in an AMS being 'oversold' to users or lead to 'measurement creep,' whereby more and more metrics are introduced to find an arguably non-existent athlete monitoring golden bullet (Lambert, 2006). Arguably, such a scenario is already apparent in published work (Akenhead & Nassis, 2016) whereby poor reported AMS efficacy was associated with not measuring the 'correct' parameters. While feasibly true, the blame for poor AMS efficacy does not lay exclusively in what can't be measured. Perhaps instead the blame lies with the inherent uncertainty associated with athletic performance combined with the quality and methodology of what is being measured (as argued in this thesis), and a failure to consider athletes in the rich and complex environment in which they exist (Vaughan et al., 2019).

Instead, practitioners should consider that a lack of (perfect) information is not necessarily the obstacle to establishing athletic readiness to train, nor to preventing illness or injury. Data inadequacy has been shown in other fields to reduce the confidence of those making complex judgements or decisions based upon a range of data. In the seminal work of Slovic (1973), horse-betting handicappers were found to have reduced confidence in their ability to rank racehorses when given less information. Despite this, increasing the amount of information they were given, while increasing their confidence, had little impact on the accuracy of their predictions.

Parallels can be drawn to athlete monitoring, where uncertainty may lead to a drive to collect more information (Ryall, 2019). Arguably, however, that information may not necessarily enhance the decision making abilities of practitioners or coaches (Pope et al., 2018; Slovic, 1973). Of course, situations exist where more data is required in order to make informed decisions; however, practitioners should be aware that seeking more data

should not form the default answer to any athlete monitoring system ills. Therefore, rather than focussing on collecting additional monitoring variables, or seeking more in-depth data on existing metrics, research on decision-making has suggested that an emphasis should instead be placed on ascertaining what value existing metrics have, and their interrelation, in order to improve decision-making capabilities (Heuer, 2008). Principle component analysis may be a useful tool to help in this endeavour (Sean Williams et al., 2017).

Measurement creep risks other undesirable outcomes, for example it may imperil the ethics of collecting athlete monitoring data, raise privacy and confidentiality concerns, and risk athletes perceiving AMS as hostile surveillance (Manley & Williams, 2019; Saw et al., 2017). Where measurement creep combines with other factors, such as poorly perceived athlete monitoring aims and objectives (Barboza et al., 2017; Saw et al., 2015b) and insufficient feedback, the subsequent engagement and buy-in of key stakeholders to athlete monitoring will likely be jeopardised, as observed in this thesis (Chapters 6 and 7).

While the philosophical debates about the value and place of athlete monitoring in elite sport continue (Coyne et al., 2018), or fail to be discussed (Bourdon et al., 2017), it is important to note that AMS are not a panacea to solve performance problems, nor to prevent health problems. Accordingly, it is suggested that, in line with research from this thesis, and elsewhere (Saw et al., 2017), the aims of athlete monitoring be revised to fall under the headings of: SUPPORTING coaching decisions, to SPEAKING, i.e. facilitate communication between the athlete/coach/key stakeholders, and to SCAFFOLDING athletes' careers to ensure AMS data is used to support a predominantly positive athlete experience of monitoring.

8.4 Conclusion

Athlete monitoring systems are typically used to aid personnel working in sporting organisations decrease illness/injury incidence and optimise athletic performance. This is particularly important in the elite sport environment, where athletes are subject to high training loads and reduced recovery periods (Halson, 2014). This therefore leaves athletes more susceptible to maladaptation (Meeusen et al., 2013). Chapter 2, and the personal experiences (see Chapter 1.2.1) of the author of this thesis demonstrated that there was a paucity of published information relating to AMS practices in elite sport. Therefore, this thesis investigated practices and perceptions of AMS by stakeholders within elite sporting organisations in Chapters 1 and 2. After identifying various issues, including poor engagement and buy-in of AMS users, reasons for poor engagement were explored in

Chapter 6 and, subsequently, an intervention which aimed to address poor athlete AMS engagement was designed and implemented in Chapter 7.

The findings from this thesis demonstrated ubiquitous use of AMS in elite sport. The customisation of AMS was common, with athlete self-report measures the most prevalent metric utilised across the elite sports surveyed in the United Kingdom. The customisation of metrics however appeared to come at a price, with reduced scientific rigour of measurement, uncertain measure validity and the reported use of inappropriate data analysis methods (Chapter 4).

This thesis argued that the issues described in Chapter 4 compounded to negatively impact practitioners' confidence in the sensitivity of their athlete self-report measures. These problems were further exacerbated by frequent reports of poor engagement with monitoring, by athletes and coaches. Poor athlete and coach engagement with AMS was a recurrent theme in this thesis (Chapters 5, 6 and 7), and in previous research (Barboza et al., 2017; Duignan et al., 2019a). However, good engagement is also pivotal for AMS success (Saw et al., 2015b). Research has previously shown that in order to change unwanted behaviours, first the reasons for the behaviour needs to be understood (Donaldson & Finch, 2012; Michie et al., 2014). The literature review and Chapter 6 highlighted however that there is not a clear understanding of the reasons behind poor athlete AMS adherence. Accordingly, Chapter 6 explored the perceptions of a cohort of elite athletes in relation to their AMS, providing a more in-depth insight into reasons for poor AMS engagement.

The athletes interviewed in Chapter 6 reported that their primary reasons for non-adherence to the AMS were: receiving insufficient feedback from the data they submitted, and a lack of transparency pertaining to how the data influenced and informed training plans. As the findings from Chapter 6 were able to elucidate some reasons for poor athlete AMS adherence, Chapter 7 ascertained the practicality of modifying poor adherence through the implementation of a formalised behaviour change intervention. It was believed that the use of a systematic and theory driven behaviour change intervention was novel in this context.

The behaviour change intervention (Michie et al., 2014) allowed construction of a feasible strategy to modify behaviour. It also encouraged a holistic examination of both the athlete behaviour, i.e. poor adherence, and the wider context in which the behaviour occurred. Some conceptual and practical shortcomings of the behaviour change intervention, such as

the lengthy process of intervention creation, and the inability to readily modify the framework, were highlighted in Chapter 7. These issues came to the fore in Chapter 7, where personnel changes rendered some of the behaviour change targets irrelevant, and the behaviour change intervention was deprioritised by staff. Therefore, while the behaviour change intervention was systematic and evidence-based, it was not easily adaptable to the changes frequently observed in elite sport (Barros et al., 2009; Gilmore et al., 2018). Finally, discrepancies highlighted in this thesis between applied practice and best practice in research were then addressed as a series of 'FAQs' in Chapter 10 in order to provide guidance to practitioners working in elite sport.

In summary, significant gaps between applied practice and research have been highlighted by this thesis. Poor scientific rigour of AMS metrics were linked with disillusioned practitioners and coaches (Chapter 5 and 7) and athletes (Chapter 6), with stakeholders often demonstrating poor engagement with the AMS. Therefore, while AMS can theoretically aid those working in elite sport to reduce the risk of injury/illness and optimise performance (Bourdon et al., 2017; Halson, 2014), unless some of the issues raised in this thesis are addressed and the guidance provided in Chapter 10 implemented, the potential benefits of AMS are unlikely to be fully realised.

8.5 Possible Future Work

This thesis has highlighted several possibilities for future research. Interventions which aim to close the gap between research and practice in athlete monitoring should be explored. This could include addressing the lack of scientific rigour behind customised AMS and determining if improved rigour has an impact on the perceived, or actual, efficacy of the AMS. Studies demonstrating the validation of customised measures, particularly athlete self-report measures may prove useful in this regard. Additionally, case studies which compare examples of successful and unsuccessful AMS practice from an ecological perspective may provide more insight into the facets of best practice in athlete monitoring.

Poor feedback processes and communication in relation to AMS are problematic within sporting organisations. What constitutes 'good' feedback practice will invariably be different between sporting organisations. However, there is currently little (Nosek et al., 2020) to no guidance on what the principles of effective feedback practice are for AMS, or on how to align feedback expectations of different stakeholders within elite sport. This is a promising avenue for exploration as poor feedback practices have been linked to poor AMS buy-in and adherence both in this thesis and elsewhere (Barboza et al., 2017; Saw et al.,

2015b). Examples of excellent feedback practices from other fields may prove helpful in guiding future studies in this area (Nicol & Macfarlane-Dick, 2006).

The role AMS data plays in informing training programme planning for elite sports coaches is little understood, with few studies examining this concept (Crowcroft et al., 2020b; Pope et al., 2018). Further research is needed in this area to help elucidate the role AMS play in coaches planning of training programmes. Any such study would need to go beyond asking what coaches want from an AMS, which has already been explored (Roos et al., 2013; Starling & Lambert, 2018), to provide more in depth detail on how AMS data informs training planning.

Finally, the behaviour change intervention utilised Chapter 7 was not able to be fully implemented. Nonetheless, the concept of using a behaviour change intervention to improve engagement with AMS remains a worthwhile avenue to explore. As noted in Chapter 7, examining the key interactions and relationships that are known to be key drivers of change within a complex system may help design an improved behaviour change intervention. This is because it would arguably be better suited to adapt to the changing demands of an elite sport environment (Keshavarz et al., 2010).

9.0 Chapter Nine - Delimitations, Assumptions and Limitations

9.1 Delimitations

Delimitations are any factors that are deemed necessary or imposed upon the respective studies by the researcher. These limits were enforced in order to keep the research within the scope outlined in the aims of the research, or for the health, safety or of the participants involved.

This study included only participants that were directly involved with elite amateur sports in the capacity of practitioners (sports science or medicine), athletes, coaches or sports science or coaching management. This was to ensure both homogeneity and representativeness within the sampling group and participant sample. In addition, all semi-structured interviews with the participants were held one-to-one with the author of this thesis to ensure privacy confidentiality and to facilitate open discussions with the participants.

The author of this thesis ensured informed consent was gained from gatekeepers, e.g. English Institute of Sport and National Governing Bodies of sport, as necessary. This enabled access to the participants who agreed to take part in these studies. However, access to run research projects with elite sporting organisations can be challenging (Fullagar et al., 2019). Therefore, the author of this thesis worked with her existing professional contacts who gave their informed consent to participate in the studies. This approach maximised the feasibility of running research projects within the elite sport environment, but also limited the range of sporting organisations that were involved.

9.2 Assumptions

Where statements are accepted as true without proof, this is termed an assumption. Several assumptions were made in this study. All participants that took part were assumed, in the main, to be truthful when reporting their practices, perceptions and opinions in relation to athlete monitoring. Further, it was assumed that the coaches in Chapter 7 ran the intervention process to the best of their abilities, as agreed in the intervention workshop, and notwithstanding the personnel changes discussed in Chapter 7.

9.3 Limitations

Limitations are factors that are imposed externally on the research undertaken, and are typically a function of the research design, or the measurement tools used. Response bias was deemed to be a limitation across all chapters of this thesis (Silverman, 2010).

9.3.1 Bias

The response rate to the surveys in Chapters 4 and 5 (at 40%) was in line with normal response rates reported in the literature (Baruch, 1999). However, it was not as high as the ideal 60% set by some journals (Fincham, 2008), and is subject to response bias. Non-response bias is where the data collected may not represent the population as a result of some invited participants being unable or unwilling to respond to the survey. This results in a systematic bias between the responders and non-responding group (Sedgwick, 2014). Non-response bias therefore poses a threat to the external validity of surveys.

Previously it has been argued that a reason for non-response to surveys includes the non-respondents feeling the survey is irrelevant (Haunberger, 2011). Within this study this could arguably encompass participants who did not have an AMS in place. However, formalised AMS are freely available via the Performance Data Management System for elite amateur sports in the United Kingdom (*Case study: PDMS*, n.d.). In addition, the use of formal AMS are often key performance indicators imposed by UK Sport and tied to funding (*Scottish Gymnastics: Performance Plan*, 2019). It was therefore deemed unlikely that invited participants did not have an AMS, whether they chose to respond to the survey or not, thus reducing the threat of non-response bias.

Further, strategies were utilised to mitigate the threat of non-response bias including recommendations from prior research, such as: the use of response date deadlines and reminders to complete the survey and to increase the response rate, the invite to participate was sent from within the institution and the survey was deliberately kept brief with mostly closed questions (Sedgwick, 2014; Silverman, 2010). Therefore, while the threat of non-response bias is acknowledged, it has been controlled for as far as possible, therefore minimising the risk to external validity.

9.3.2 Data clustering

Surveys can be at risk of data clustering, i.e. grouping of response data as a result of the participants sharing similar characteristics, which can bias data. This is a concern if multiple people from the same sporting organisation or team respond to the survey. While some previous surveys have only permitted one response per team to avoid this issue (Harper et al., 2016), others have allowed this when there were different squads within teams, i.e. differentiated by gender of the squad or sporting discipline (Weston, 2018). In Chapters 4 and 5, multiple responses from the same sporting organisations were included; however,

respondents were differentiated by the gender of the squad they worked with and their sporting discipline. It is acknowledged that this could lead to clustering of responses in relation to practices of athlete monitoring, but not in relation to perceptions of athlete monitoring. If only one respondent from each sport was included in the response data, the sample size would have been smaller. Given the low numbers of people working in elite amateur sport in the United Kingdom, this balance between potential data clustering vs. sample size was felt to be a reasonable compromise.

9.3.3 Transferability

Most studies in this thesis took an observational approach to data collection, e.g. using surveys or semi-structured interviews to collect data. The exception was Chapter 7, where an intervention was applied. The hierarchy of evidence pyramid (Murad et al., 2016) would place the work undertaken in this thesis under a 'case study' axiom. This is usually associated with better external validity, i.e. the generalisability to different settings, but lower internal validity, i.e. the ability to discern cause and effect within a relationship (Steckler & McLeroy, 2008).

The hierarchy of evidence pyramid can lead us to dismiss the value of studies with lesser internal validity. Nonetheless, studies with greater internal validity, i.e. randomised control trials, are underpinned by models of simple linear causality (Greenhalgh & Papoutsi, 2018). Sporting organisations are however complex systems, and simple models of Newtonian cause and effect likely do not hold true (Gomersall, 2018). Instead, there may be complex chains of causality which lead to athletes or coaches (dis)engaging with an AMS, as seen in this thesis (Chapters 6 and 7). In the elite sport environment it is challenging to plan intervention-based research (Coutts, 2017) and recruit control groups (Gathercole et al., 2015). Therefore, this thesis faced both conceptual and theoretical issues relating to the assumption of linear causality in a complex system, and practical limitations relating to feasibility of study design in an elite sport environment. Accordingly, it was felt that observational case studies provided good external validity, that were both feasible and provided rich insight to improve our understanding of how athlete monitoring systems work within elite sport.

Generalisability or transferability, are terms primarily used in relation to quantitative and qualitative research respectively (Silverman, 2010). These terms refer to the ability of the findings from a study to be applicable in settings beyond that described in the study (Leung, 2015). As two of the studies in this thesis refer to participant cohorts in specific

sporting organisations, the possibility to transfer these findings to wider settings is limited. Pragmatically, however, while each sporting organisation is unique, similar themes permeate the elite sport environment. For example, they are governed by the same overall funding arrangements, they are all focussed on success on the Olympic and World stage, and subject to similar key performance indicators (*How UK Sport funding works | UK Sport*, n.d.). These cross-sport similarities were also observable within the findings of this thesis (Chapters 4 and 5), as well as in more detailed case-study exploration of specific sports (Chapter 6 and 7). Accordingly, although elite sporting organisations clearly vary by nature, underpinning similarities in their governance, structures and the issues they face, e.g. use of AMS, allow more transferability in the findings of this thesis between sports than might otherwise be thought. Therefore, despite some chapters of this thesis focussing on different sports, it was felt that there was enough evidence that different sports are impacted by similar AMS issues (Saw et al., 2015b), to rationalise the multi-sport analysis approach employed. Indeed, such an approach may lend further strength to the thesis findings due to the heterogeneity of sports sampled within the participant cohort.

9.3.4 Trustworthiness

A limitation of qualitative research is establishing the trustworthiness or the data, i.e. factors such as data credibility and rigour (Silverman, 2010; Tracy, 2010). Historically, some of the main methods used to ascertain the scientific rigour of qualitative research have been member-checking and inter-rater reliability (Silverman, 2010; B. Smith & McGannon, 2018). In this thesis, member-checking was used to permit discussion between the participants and researchers to help ensure the veracity of the research findings (Silverman, 2010). There has however been recent criticism of the use of member-checking as an effective method for assuring scientific rigour in qualitative research (B. Smith & McGannon, 2018). Philosophical arguments relating to the ability of researchers to achieve theory-free knowledge, and therefore objectively assess their qualitative research, have yet to be resolved. Additionally, practical problems pertaining to the time lag between data analysis and member-checking occurring and power relations between researchers and participants have also been raised as issues that may reduce the effectiveness of member-checking. The author of this thesis therefore acknowledges that while member-checking may help establish trustworthiness, it comes with methodological issues.

One of the other methods predominantly used to demonstrate scientific rigour in qualitative research is inter-rater reliability. Inter-rater reliability as a method for

establishing the reliability between researchers in their thematic coding was not used in this study. This occurred for several reasons: firstly due to changes in the supervisory team during this PhD thesis, and secondly because this method has been argued to be ineffective at establishing the reliability of qualitative research, due to an inability for researchers to produce theory-free knowledge (B. Smith & McGannon, 2018). Therefore, in line with recommendations from the literature (B. Smith & McGannon, 2018), members of the supervisory team were instead used as critical friends to discuss and challenge the findings of the semi-structured interviews and to encourage reflexivity.

10.0 Chapter Ten - Practical Applications

Findings from this thesis have highlighted areas where those working with an AMS in elite sport may face challenges. Therefore, the following chapter extends existing guidelines for athlete monitoring in elite sport (Saw et al., 2017), to address some of the core issues outlined in this thesis. Specifically, the stages of the athlete monitoring process (inception/planning, data collection, analysis and feedback) are explored, with best practice recommendations highlighted from the findings of this thesis and the literature. These practical applications are considered in a frequently asked questions (FAQs) format, where questions are posed which stakeholders should consider in relation to their AMS. The questions are then subsequently addressed, nuances explained, and, where relevant, examples of 'best practice' given. This practical applications chapter is meant to provide a practical 'handbook' for the applied practitioner and other stakeholders who have, or are, thinking of implementing an AMS within their sporting organisation.

While the questions addressed below aren't meant to be exhaustive, they comprise some of the key factors to consider when using an AMS. These questions have been drawn from findings from this thesis. Accordingly, evidence and examples from this thesis are used to address the questions posed below.

Table 10. Considerations for the applied practitioner when planning and implementing an athlete monitoring system

AMS Area	Frequently Asked Questions
Purpose	1. What is the rationale/need for having an AMS within your sporting organisation?
	2. What is the aim of the athlete monitoring system within your sporting organisation?
Culture	3. What role will AMS data have in decision-making within your sporting organisation?
	4. What access should athletes have to their own data?
	5. What if my sporting organisation has successful athletes that aren't using the AMS?
Buy-in	6. How do I achieve AMS buy-in with stakeholders?
	7. Should consequences (carrot and stick) be implemented to enhance athlete buy-in?
Questions	8. Are the measures you are using in your AMS validated?
	9. How many metrics do you REALLY need?
	10. What athlete self-report questions should be included in an AMS?
Responses	11. How should responses to custom athlete self-report measures be constructed?
	12. How do we avoid the process of athlete monitoring reinforcing fatigue levels?
	13. Should we allow retrospective completion of AMS data?
Data Analysis	14. What is considered 'best practice' in AMS data analysis?
Feedback	15. What is 'best practice' for giving feedback on AMS data to athletes and coaches?
Other considerations	16. Technology and the AMS: help or hindrance?

10.1 Purpose: Athlete Monitoring Rationale and Aims

As discussed in Chapter 8, the inherent uncertainty associated with athlete monitoring means that searching questions need to be asked about the role of athlete monitoring within elite sport. The reductive philosophy of athlete monitoring as a panacea for performance optimisation or injury/illness reduction does not appear to hold true, given the findings from this thesis, and the uncertainty and complexity of real-life in elite sport (Gomersall, 2018; Jovanovic, 2017). Therefore, sporting organisations should consider the following questions, in conjunction with Figure 13, in relation to their athlete monitoring. These 'FAQs' extend existing guidelines (Saw et al., 2017) and aim to provide a useful resource to those working in elite sport.

What is the rationale/need for having an AMS within your sporting organisation?

Nuances: Embarking on implementing an AMS can be very logical and an easy path to pursue, as many others in the industry have already 'set the example' (Burgess, 2017;

Taylor et al., 2012). However, doing so without setting out a prior need or rationale for AMS use with all relevant stakeholders, particularly the coaching team, may result in an AMS that is inappropriate or that results in poor buy-in (Saw et al., 2015b). Be aware that the specific rationale or need for an AMS is rarely discussed in published research; instead indeterminate phrases relating to AMS aims such as 'predicting illness' maybe used (Gabbet, 2016).

Evidence: Within this thesis, 12% of practitioners did not have a clear rationale underpinning the use of their AMS. These respondents indicated a lack of clarity pertaining to what it was they were trying to achieve from their AMS data collection, with mixed messaging apparent from within the sport. Furthermore, disparities in the rationale for AMS use were apparent between the coaching team and the athletes in Chapter 7. This indicated that even where the coaching team and/or practitioners within a sporting organisation had a clear rational for AMS use, failure to set clear athlete expectations in how the AMS was applied resulted in an expectation mismatch.

This thesis extends existing work (Saw et al., 2017) to suggest that a more systematic assessment of the purported 'need' for an AMS is conducted by those in the sport organisation. Strategies such as using a needs-analysis, e.g. an analysis of strengths, weaknesses, opportunities and threats (Gürel & Tat, 2017), to systematically identify the need for an AMS would support this approach (see Figure 13). Where appropriate, involving members of staff and athletes in the needs-analysis may help avoid expectation mismatches between team members.

Example: "We have identified that during intensive training blocks we push some athletes into non-functional over-reaching and are getting anecdotal reports of excessive fatigue. We would like to get a deeper understanding of what is occurring during these periods of time."

What is the aim of the athlete monitoring system within your sportinf organisation?

Nuances: The identified need for an AMS should inform the aims of your AMS. Aims should be specific to your sport organisation. Avoid defaulting to the standard AMS aims that are frequently discussed in the literature.

Evidence: Within this thesis, the main aims of athlete monitoring were reported to be injury/illness prevention and optimisation of athletic performance (Chapter 4). The use of AMS to prevent illness/injury and to optimise performance are consistent with what has

been reported in the literature (Halson, 2014; Taylor et al., 2012). Findings from Chapter 7 showed that other AMS aims were in use however, with these coaches reporting their AMS was primarily used to increase athlete professionalism.

As discussed in Chapter 8.3, there is inherent uncertainty associated with our understanding of an athlete's training status. This is primarily a result of the complexity of the elite sport environment (Cruickshank & Collins, 2012) and the multifactorial nature of illness, injury and performance (Bourdon et al., 2017; Roe et al., 2017). Therefore, it is important that AMS aims are specific measurable, achievable, relevant and time-bound, rather than being vague and indeterminate (Bjerke & Renger, 2017). Practitioners surveyed in this thesis reported illness and injury prevention as a key aim for athlete monitoring within their sporting organisation (Chapter 4). It is important that practitioners continue to delineate injury/illness prevention from illness/injury prediction. As, despite assertions to the contrary (Hulin et al., 2014), the prediction of illness or injury from AMS data does not yet appear possible (Impellizzeri et al., 2019, 2020; Jovanovic, 2017). Therefore, it is recommended that the use of terms such as forecast or prediction for AMS aims should be avoided.

When the aims of an AMS do not align with stakeholder expectations, or the sporting organisation is unable to deliver the AMS aims they set out, it is likely to risk athletes, coaches and even practitioners becoming disengaged with the AMS. These issues were seen in this thesis in Chapters 6 and 7. Therefore, it is particularly important that there is coherence between the aims of the AMS as understood by the coaches, practitioners, athletes and management. Expectations in relation to AMS aims should therefore be clear from the outset. In order to set expectations and ensure agreement within the sporting organisation, it may help to clarify what a 'successful' AMS will look like from an athlete/coach/practitioner perspective. This should include what the AMS is (and will do), and what it is not (and won't do). Consideration should also be given to how achievement of the AMS aims can be evidenced to all stakeholders, within a timely fashion.

Finally, if the aims of the AMS cannot or are not met within the agreed timelines, thought should be given to what remedial actions are taken. This could include building in formal 'AMS review points.' Here, all stakeholders should reflect on the utility of the AMS, if it has met its aims and whether the use of it should continue. Engaging athletes in this process may help foster their feelings of autonomy (Deci & Ryan, 2002), as this was discussed as a factor that likely impacts athlete adherence in Chapter 2.7.4, Chapters 6 and 7. Review

points would also be useful where significant operational changes occurred within the sporting organisation, for example, the changes in personnel observed in Chapter 7. In Chapter 7, it was apparent that the deprioritisation of the behaviour change intervention resulted from an implicit understanding between the coaching staff, rather than as part of a more formal review process. A more formal review of the role of AMS would have perhaps aided the communication between the athlete and coaching team and re-established the role of the AMS in light of the operational changes occurring within the sporting organisation.

Example: *"*Our sporting organisation's aims for the AMS are to: (1) Increase both formal and informal conversations between the coach-athlete dyad. (2) To reduce athlete/coach/practitioner uncertainty in relation to performance by collecting pertinent data to support informed programmatic decisions. We will measure our progress through (surveys/informal conversations with the team/adherence rates) and revisit out progress in relation to the aims every 3-months.

10.2 Athlete Monitoring Systems and Sporting Culture

Rather than empowering athletes to be reflective and autonomous, increasingly there is an argument that athlete monitoring systems have the potential to negatively impact the culture of an organisation. More specifically this is argued to occur through propagating fear of hostile surveillance and adversely impacting athlete mental health (Manley & Williams, 2019; Shaun Williams & Manley, 2016). While this argument has been disputed (Collins et al., 2015), the findings from this thesis support concerns that athlete monitoring can result in athletes, and even practitioners becoming disenfranchised with athlete monitoring. Accordingly, sporting organisations should consider the following question in relation to the culture surrounding their AMS.

What role will AMS data have in decision-making within the sporting organisation?

Nuances: The careers and financial security of those working in elite sport are primarily determined by results (*How UK Sport funding works | UK Sport*, n.d.). Therefore, if the data from an AMS is used to determine sensitive parameters such as team (de)selection or funding, there is a risk of adversely impacting the perception athletes have of an AMS.

Evidence: Evidence from this thesis indicates that athletes had mixed perceptions of their AMS, with some finding it a useful tool to reflect upon their progress. Others voiced

concerns about the data being used inconsistently, or disproportionate training modifications being made by staff in response to the data (Chapters 6 and 7). This led to some athletes reporting they were untruthful in their reporting practices in order to subvert fears of inappropriate reprisals (Chapter 6.3.4). Some of these concerns had subsequent implications, for example the survey results in Chapter 5 indicated that practitioners felt their confidence in their AMS metrics was negatively impacted by untruthful athlete reporting practices.

Therefore, the tone and communication of the intention behind how AMS data will or won't be used by the sporting organisation is critical to avoid a culture of hostile surveillance (Manley & Williams, 2019; Shaun Williams & Manley, 2016). Practitioners should ensure that the tone and intention of the AMS reflects its aims and needs, as discussed earlier in this chapter. This helps to ensure consistency and coherence in AMS messaging. Findings from this thesis have indicated that the use of punitive measures or coercive practices to increase athlete adherence to their AMS may not go as planned (see Chapter 7). Accordingly, it is suggested that punitive measures are avoided or used sparingly, and an AMS should be positioned to enhance rather than detract from an athlete's experience. As athletes are however ultimately judged on performance, there should be transparency around if, when, and how any AMS data is used for more sensitive purposes such as team selection. This could form part of an AMS 'charter' which outlines the role of the AMS in more detail. If AMS data is required for more sensitive purposes, it is advisable that the use of AMS data for such practices is delineated from collection of 'standard' athlete monitoring data. This may help ensure continued buy-in from athletes and prevent the perception of constant scrutiny which can cause significant athlete anxiety (Manley & Williams, 2019; Shaun Williams & Manley, 2016).

Example: The sporting organisation has a written AMS 'charter' which clearly outlines the role and expectations of AMS data collection and feedback. All stakeholders have sight of the document and are co-creators and signatories to its content.

What access should athletes have to their own data?

Nuances: Typical AMS allow athletes access to some of their data through use of an integrated 'dashboard,' that summarises AMS data in an accessible format (*Case study: PDMS*, n.d.). Nonetheless, not all data, particularly historical or analysed data and feedback is readily available to the athlete.

Evidence: Chapter 6 indicated that this cohort of athletes did not have access to their historical AMS data. Similarly, Chapters 4, 6 and 7 demonstrated that feedback to athletes was often insufficient. Data silos, which have been reported previously in the literature can exacerbate this issue further through increasing barriers to data accessibility (Dijkstra et al., 2014; Duignan et al., 2019a). Where an inability to access datasets is combined with a lack of feedback, athletes can become frustrated regarding the role and utility of the AMS (Chapters 6 & 7). Other published research has also shown that fears of the data being used in a deceptive manner is heightened and erosion of the confidence in management occurs when athletes' access to their AMS data is restricted (Manley & Williams, 2019).

Sporting organisations will also need to consider the role of General Data Protection Regulations (*Guide to the General Data Protection Regulation - GOV.UK*, 2018), and privacy and confidentiality concerns that come with collecting personal data. Athlete monitoring data collection may also pertain to medical records which are governed by additional regulation (*Legislation and guidance relating to medical records explained by House of Commons Library - NHS Confederation*, n.d.).

Therefore, athlete access to AMS data walks a fine line between transparency, maintaining the trust of the athlete, technological capabilities and ensuring adherence to data protection legislation. Each sporting organisation will therefore need to be guided by their own circumstances, but this thesis indicates a leaning towards more rather than less transparency is warranted, and this is supported by other research in this area (Manley & Williams, 2019). Further, it is likely that there will be no easy technological solution to allow access to historical data and access to data across multiple different platforms. This may lead to data silos as discussed in the literature review (Chapter 2). The potential shortcomings of information technology should therefore be considered as part of AMS planning and implementation (Figure 13).

Example: The sporting organisation has clear idea of where data silos exist, they understand the technological capabilities of their AMS, and data protection. Any limitations technology may cause are discussed with all stakeholders, and where necessary, mitigation procedures are put in place to ensure data is shared as deemed appropriate.

What if my sport has successful athletes that aren't using the AMS?

Nuances: This has a reasonably high likelihood of occurring, such situations need to be managed with care.

Evidence: In this thesis, 58% of practitioners in Chapter 5 reported that they worked with internationally successful athletes that did not complete the athlete monitoring prescribed by their sport. This finding is also supported by researchers (Buchheit, 2017). As observed in Chapter 7, there is however no magic bullet that can bring about radical change and increase athlete AMS adherence in such a scenario. Further, research has shown that it may also be particularly challenging to modify behaviours in athletes that are already very successful (Halson & Lastella, 2017).

If the sporting organisation does decide that all athletes should adhere to the AMS, it would be wise to initiate discussions regarding the poor acceptability of punitive consequences to promote AMS adherence. This is because punitive consequences are often seen as an 'easy' solution (Chapter 5). The potential pitfalls and unintended consequences than can arise from a top-down approach to implementing behaviour change interventions to increase adherence should also be considered (see Chapter 7). If the sporting organisation does not call for blanket AMS adherence, practitioners should instead work with the MDT and coaching team to carefully manage the optics of high-profile athletes failing to adhere to the AMS, for example, refocussing the debate on what monitoring these athletes do complete. This is to prevent other athletes perceiving there is 'one rule for them, another rule for us.' Failure to address these concerns risks poor behaviour modelling and contagion of emotions such as frustration or ambivalence towards the AMS (Wagstaff et al., 2012).

10.3 Engagement and Buy-in to the Athlete Monitoring System

How do I achieve AMS buy-in with stakeholders?

Nuances: Buy-in (in particular athletes and coaches) has been identified as a significant issue to AMS implementation, without it an AMS is unlikely to be successful.

Evidence: To date, no clear definition of buy-in has been published that is relevant for sports scientists. Therefore, this thesis used an operational definition of: 'an individual's cognitive (attitude and beliefs) and behavioural (actions) commitment to the AMS,' adapted from Mathews and Crocker. (2014). Poor buy-in from athletes and coaches has been identified as a significant barrier to implementing a successful AMS, and this has been reported throughout this thesis.

Practitioners should be aware that based on the findings from this thesis and the literature review, no magic bullet exists that will drastically increase buy-in to an AMS, but there are strategies which may improve buy-in. Practitioners should consider using a behaviour change intervention such as the behaviour change wheel (Michie et al., 2014), to help them formulate a framework to address poor buy-in. Such an endeavour comes with a warning that behaviour change interventions such as the behaviour change wheel (Michie et al., 2014), are neither a panacea to address poor buy-in, nor are they easily adaptable to changes in structure/personnel or funding etc that may occur within a sporting organisation. Nevertheless, behaviour change interventions provide a systematic and methodological approach to addressing issues of poor buy-in (Michie et al., 2014). They will also encourage adoption of strategies beyond the standard athlete education sessions which were otherwise observed as normal practice (see Chapters 6 & 7).

Other strategies to gain buy-in include identifying and focussing on key interactions or relationships which may positively impact buy-in. In the elite sport environment this is likely to be the coach-athlete relationship (Keshavarz et al., 2010). This is important because as outlined in this thesis, one potential route to enhancing athlete AMS buy-in is to ensure the coaches are engaged with the AMS.

This thesis also indicated that where a coaching team was in place for an athlete, discrepancies in how the coaching team utilised the AMS, caused the athletes significant concern, and may have contributed to their lack of engagement with the AMS (Chapter 7). Therefore, quality assurance between coaching approaches to AMS use is advisable to address such differences. While it is likely unfeasible to get a completely uniform approach to AMS use between coaches, items such as athlete monitoring data feedback and transparent decision making should be non-negotiable. As discussed earlier in this chapter, setting athlete expectations may help manage any smaller variations in coaching approach.

Example: Features of an environment where an AMS engages key stakeholders include: regular conversations between the coach/athlete/practitioner which are informed by data from the AMS, athlete adherence ≥70% of expected, coaches actively seeking out AMS data, coherence between coaches approach to AMS use, and increased athlete reflectivity and ownership of AMS data.

Should consequences (carrot and stick) be implemented to enhance athlete buy-in?

Nuances: Punitive consequences or rewards can be used as tools to enhance athlete buy-in to an AMS – however, should they be used?

Evidence: Where punitive consequences were applied within this thesis they were generally dimly viewed by athletes (Chapters 6 & 7). Where practitioners had punitive consequences in place (Chapter 5) a 'grass is greener' effect existed, where those without consequences in place wanted to implement them, and those with them in place wanted to remove them. Accordingly, it appears sensible to approach the use of punitive consequences with great care. Particularly as they may further promote athlete perceptions of an aggressive or hostile AMS experience (Manley & Williams, 2019), or promote untruthful reporting practices (Saw et al., 2015b). Where punitive consequences are applied it will be important to consider how to implement them consistently and uniformly, so athletes don't feel they can be easily subverted or evaded (see Chapter 6).

Strategies to reward adherence were also employed within this thesis after use of the behaviour change intervention in Chapter 7 (Michie et al., 2014). Athletes reported little awareness of these measures (see Chapter 7), but they resulted in some unintended consequences. For example, the use of a leader board within the training centre to celebrate good athlete adherence to monitoring unintentionally began to celebrate poor adherence when adherence dropped (Chapter 7). Therefore, careful thought should be given to any potential unintended consequences that may arise from the use the use of punitive or reward -based approaches to promote buy-in to the AMS.

10.4 Questions and Measures in Athlete Monitoring Systems

Are the measures you are using in your AMS validated?

Nuances: Athlete monitoring measures from peer-reviewed sources are typically validated for construct and/or criterion validity (Kellmann & Kallus, 2016). When custom measures are created and used within a sporting organisation, it is not possible to determine if they can measure the parameter they purport to without scientific validation. Practitioners in particular may feel pressure to customise athlete monitoring measures in order to make them sport-specific and brief (Taylor et al., 2012). However, this goes together with a risk of the metric then failing to be valid. Before embarking on validation exercises, practitioners should familiarise themselves with the theoretical concepts of

criterion, content, face and construct validity discussed within Chapter 2.1.1 of this thesis and decide what aspect of validity they are pursuing (Gratton & Jones, 2010).

Evidence: The widespread use of custom measures within AMS, particularly athlete self-report measures was demonstrated in this thesis (Chapter 4), with similar findings reported in elite Australasian sport (Taylor et al., 2012). Difficulties in assessing athlete monitoring data for meaningful change were also highlighted by participants in Chapter 4, alongside only 52% of respondents reporting confidence in the sensitivity of their athlete monitoring metrics. Methods to validate custom metrics are typically time-consuming and likely impractical for an applied elite sport context. Therefore, in order to address poor or unknown measure validity, researchers have suggested alternatives such as unified validity theory (Windt et al., 2018), inclusion of expert opinion (Kyprianou et al., 2019), and a paradigm shift of using subjective measures to validate objective athlete monitoring measures (Coyne et al., 2018). This thesis has shown that a step change is needed to ensure the metrics used in AMS are valid, and thus engender confidence from the end-users in their AMS data.

How many metrics do you REALLY need?

Nuances: Research philosophies have previously stated a law of diminishing returns as the number of data collection measures increases (Slovic, 1973). While valid and sports specific metrics are central to an athlete monitoring system, arguably, more metrics does not necessarily equal a better AMS.

Evidence: Athlete monitoring data is collected to help inform coach training programme planning and in accordance with a duty of care to the athlete (Halson, 2014; J. S. Thornton, 2020). This thesis has however demonstrated that coaches' engagement with the data from AMS tends to be weak, with less than half of respondents in Chapter 5 reporting full support for the AMS from their coach. Similar reports of poor coach engagement with AMS data have also been highlighted elsewhere (Crowcroft et al., 2020b; Pope et al., 2018; Saw et al., 2015b). When poor coach engagement is paired with uncertain measure validity and poor practitioner confidence in the sensitivity of measures (Chapters 4 and 5), there is a risk practitioners will try to ameliorate the situation by implementing more and more metrics resulting in measurement 'creep' (Vaughan et al., 2019).

Practitioners should therefore focus on improving the understanding of their existing metrics rather than defaulting to measuring more if they feel under pressure to improve their AMS. Ascertaining the validity of metrics as detailed above, focussing on performance measures, and prioritising subjective measures of athlete training status over objective may help in this endeavour (Coyne et al., 2018). As measures can often be inter-related, avoiding statistical issues of multicollinearity through reduction of datasets via principle component analysis has been advised (Sean Williams et al., 2017) Ascertaining how, or if, measures contribute to coaches decision-making processes will also help streamline data collected.

What athlete self-report measures should be included in an AMS?

Nuances: There is an infinite number of questions you could ask your athletes in a custom AMS. While each sport will be unique in its demands, there are some similar questions or constructs that each sporting organisation should consider.

Evidence: A significant variety of athlete self-report measures were reported in Chapter 4 (Figure 7). Sleep quality, muscle soreness and illness/injury status were amongst the most popular questions to ask athletes, with similar findings reported in the literature (Gastin et al., 2013; Saw et al., 2015c; Taylor et al., 2012). These questions may therefore be useful and sensitive to changes in athlete training status in the elite sport environment. The responsiveness of questions pertaining to sleep quality has however been questioned (Saw et al., 2015c), but rebutted in this thesis (Chapter 2.3 and Chapter 4), therefore, inclusion of self-report sleep questions are recommended as part of an AMS

Chapter 6 indicated that some athletes found the self-report questions difficult to understand and interpret. Therefore, it appears good practice to have clear operational definitions for any parameters measured. Further, agreement between the athletes/coaches and practitioners on how each self-report parameter is defined and how to deal with any idiosyncrasies of reporting practices should be established. For example, Chapter 6 demonstrated athletes found the session RPE for time trials and competitions performances not reflective of the actual load experienced. Clarifying misunderstandings relating to terminology or use of the AMS is therefore important to ensure athletes feel their responses accurately represent their perceived load.

Poor question clarity could be addressed by including written definitions for self-report parameters within the AMS that are viewable in conjunction with the question. The

operational definitions attached to questions should be agreed in education sessions with key stakeholders. Inclusion of a time of day within a question i.e. “How fatigued do you feel this morning?” can increase question specificity (Peterson, 2014). Any misunderstanding of self-report questions may impact their subsequent sensitivity or utility, therefore alongside the important constructs of specificity, brevity and validity of any AMS questions, practitioners should also consider the clarity of their AMS questions.

10.5 Responses to Custom Self-Report Athlete Monitoring Questions

How should responses to custom athlete self-report measures be constructed?

Nuances: Rarely will a published athlete self-report tool fit what your sporting organisation wants from an AMS. Accordingly, if you are deciding to employ custom measures, or already have them, some factors to consider in relation to response scales are discussed below.

Evidence: The majority (96%) of respondents in the survey in Chapter 4 who had an AMS indicated they used custom athlete self-report measures. While the use of validated tools that have been published and critiqued in the literature may make sense to those who are removed from frontline work in elite sport. The reality is that their use does not appear to occur with any frequency in applied practice (see Chapter 4). Therefore, some recommendations for custom response scales are briefly discussed below.

If you are using Likert response scales (as did 84% of respondents in the survey in Chapter 4), it is best practice to use written descriptive anchors that are associated with the numerical points on your scale, examples are available from the literature (Vagias, 2006). As discussed above, any potential ambiguities in response scale interpretation should be discussed with athletes and addressed prior to implementation. Chapters 6 and 7 give some insight into what can happen if athletes misunderstand their self-report questions/responses.

The length of the scale matters. Research has demonstrated Likert scales should be between 4 and 7 points, beyond that the discriminatory capacity of the individual is exceeded and reliability and validity of the scale is not increased further (Lozano et al., 2008). Chapter 4 indicated that several other practitioners used a percentage scale, as discussed above the use of such a scale will likely exceed the discriminatory capacity of the individual, potentially resulting in scores clustered around few data points (Peterson, 2014).

How do we avoid the process of athlete monitoring reinforcing fatigue levels?

Nuances: It is fairly typical for elite athletes to 'always' report they are tired. This is not surprising given the intensive training programmes in which they participate in order to compete at an international level (Pope et al., 2018). Practitioners should however be aware that asking athletes to reflect on their fatigue levels as part of monitoring can risk reinforcing or exacerbating these concerns.

Evidence: The issue of inadvertently reinforcing fatigue levels of athletes through monitoring has been reported from an athlete perspective in this thesis (Chapter 6) and is supported from both coach and practitioner perspectives elsewhere (Pope et al., 2018; Saw et al., 2015b). Not all athletes surveyed in this thesis indicated that monitoring caused them this issue, however, where this is a problem, practitioners may want to reconsider the timing of their monitoring. For example, reducing monitoring around sensitive competition periods. Further, practitioners should consider how their AMS questions are phrased. For example, asking "how fatigued are you in comparison to normal?" may decrease the emphasis on fatigue levels in comparison to "how fatigued are you today?" (Rushall, 1990). Finally, if athletes are habituated to their AMS, and practitioners AND coaches feel AMS completion is necessary during sensitive time periods (i.e. around competitions), practitioners may want to consider alternative methods to collect this data. For example, verbal data collection only. Alternatively, practitioners may want to explore strategies in partnership with the sports psychologist to mitigate the impact of mandatory AMS reporting.

Should we allow retrospective completion of AMS data?

Nuances: Athletes forget to complete their monitoring, it has and will continue to happen, how best should practitioners approach this issue?

Evidence: Within this thesis, significant issues with athlete adherence were found, this is supported by wider research (Barboza et al., 2017; Saw et al., 2015b). Where athletes forget to complete their monitoring, it may be tempting for practitioners to recommend athletes complete their monitoring retrospectively. This is of concern given the discussions in Chapter 8 pertaining to the underlying reductionist philosophy of sports scientists. This can fuel a need for extensive and complete datasets in order to understand an athlete's training status (Vaughan et al., 2019).

The accuracy of recall in relation to athlete monitoring has received little research attention. What research has been completed has mainly focussed on recall surrounding competitions, which arguably maybe more memorable than regular training. However, track and field athletes were found to be able to accurately recall pre-competition anxiety levels two days after following competition (Harger & Raglin, 1994), but with frequency of symptoms recalled more accurately than intensity (Thomas et al., 2011). However, recall accuracy and bias has been studied extensively in allied fields, and while findings have varied, it is apparent that over-reporting of symptoms frequently occurs when participants are asked to recall information (Van Den Bergh & Walentynowicz, 2016), and the accuracy of recall falls after time (Rubin & Wenzel, 1996). Therefore, care should be taken with data completed retrospectively, and practitioners may instead want to explore statistical methods that deal with missing data (Scheffer, 2002).

10.6 Analysis of Athlete Monitoring Data

What is best practice in AMS data analysis?

Nuances: There are a plethora of different statistical approaches to analyse AMS data, therefore, selection of the most appropriate analytical approaches can be challenging.

Evidence: Selection of the most appropriate method to analyse data from AMS will be specific to the type of data analysed, whether it is individual or group data, and the type of sport. It will also be heavily influenced by the coaches' requirements (Roos et al., 2013; Starling & Lambert, 2018). In this thesis, the data analysis methods practitioners used primarily included raw scores, rolling averages and percentages. Meaningful change was reportedly analysed through use of raw scores, acute to chronic workload ratios and smallest worthwhile change. While no single method can be championed over others in AMS data analysis, due to variability in the type of data individual sporting organisation collected, some generic principles can be applied and are discussed in more detail below.

Individual Data:

Frequently, sports scientists analysing AMS data will need to assess whether the data they are examining has changed meaningfully at the individual level. This is challenging as conventional routes, such as increasing sample size to compensate for low signal to noise ratio, cannot be employed. Further, sources of noise or error, such as measurement error (Hopkins, 2000; Nevill et al., 2016) and individual variation (Hecksteden et al., 2015), are

not easy to ascertain or control. This is because practitioners may need to implement repeated testing, the use of control groups or wash-out periods in order to understand the 'noise' in relation to their signal. Unfortunately, these approaches will likely be impractical in the elite sport environment. However, guidelines for achieving a statistically robust approach to analyse data in the individual athlete have been published and give some pragmatic alternatives for the applied practitioner (Atkinson et al., 2019; Hecksteden et al., 2015; H. R. Thornton et al., 2019).

In relation to training load data, it is important to note that acute to chronic workload ratio is unable to predict injury (Chapter 2.5). It also suffers from significant statistical issues pertaining to scaling and discretization of data (Carey et al., 2018; Lolli et al., 2019a, 2019b). Therefore, the use of the acute to chronic workload ratio to predict injury should be avoided. There are some indications from both this thesis (Chapter 4) and elsewhere (Maupin et al., 2020) that the ratio continues to be used by practitioners, presumably as it is felt that it can provide a guide for training load planning. Where this occurs practitioners should be aware of the shortcomings of the acute to chronic workload ratio. In particular they should consider the issues that it presents in relation to data biases and scaling errors (Lolli et al., 2019b) and consider alternatives (T. Richardson, 2020). Where moving averages are used to analyse training load data, it is advisable to employ exponentially weighted moving averages in preference to rolling averages (Atkinson et al., 2019; Hecksteden et al., 2015; Menaspà, 2016; Murray et al., 2017; H. R. Thornton et al., 2019). This allows improved consideration of the time course and variations of when a stimulus occurred, and the decaying effects of fitness and fatigue over time. Single study case designs may also provide value in ascertaining the impact and efficacy of the AMS from a qualitative perspective (J. B. Barker et al., 2013).

Group Data

Traditionally, making inferences from group data in sports science falls to the realm of null hypothesis significance testing. Guidance and information on limitations of this approach can be readily found in the literature (Cumming, 2014; Greenland et al., 2016). However, no practitioners surveyed in Chapter 4 indicated they used such approaches. More recently statistics in applied sport science have advocated approaches such as the somewhat contentious use of magnitude-based inferences (Batterham & Hopkins, 2006; Buchheit, 2018; Hopkins, 2004). This approach can be used in individual or group data but has received criticism for being prone to making Type I errors (Sainani, 2018), however this has

been refuted (Batterham & Hopkins, 2019). Nonetheless, some practitioners in Chapter 4 reported that they used the smallest worthwhile change as an indicator for assessing meaningful change within their cohort of athletes. Other suggested methods to analyse group data have included the use of means, standard deviations and Z-scores (Gabbet et al., 2017; H. R. Thornton et al., 2019).

10.7 Feedback of Athlete Monitoring Data

What is 'best practice' for giving feedback on AMS data to athletes and coaches?

Nuances: Athlete monitoring systems should have established feedback processes in place (Saw et al., 2017). Creating effective feedback processes that meet the demands of all stakeholders, while balancing existing workloads is, however, likely to be challenging.

Evidence: Current feedback practices were identified as insufficient by many athletes, coaches and practitioners in this thesis (Chapters 4, 6 and 7). Further, several athletes reported that their AMS adherence was contingent on receiving feedback. The identification of this relation is important, as positively influencing feedback practices may increase athlete adherence (Barboza et al., 2017). Chapter 6 also identified differences between the stated expectations of feedback frequencies athletes had (approximately every 25 days), which was contradicted by the irritation athletes expressed if their daily changes in AMS scores were not scrutinised. It is advisable, therefore, that sporting organisations set clear and agreed expectations on feedback frequencies and content which are achievable. As far as possible, these expectations should also satisfy the feedback requests of the athletes who are providing the data.

What constitutes good feedback practices in relation to AMS in elite sport will invariably differ between sports, but findings from this thesis indicate that athletes value pattern contextualisation (current vs. historical) and identification of meaningful changes (Chapter 6). Other research in this area has also identified the need for clear roles and responsibilities in relation to the processing and discussion of feedback (Saw et al., 2017). As discussed earlier in this chapter, the transparency of coaching decisions that relate to athlete monitoring data feedback are critical. Therefore, unless deemed necessary, situations where AMS data informs coaching decisions but is not shared with the athlete should be avoided to prevent exacerbating fears of hostile surveillance (Manley & Williams, 2019). Further research is needed in this area to help provide more guidance to practitioners on what constitutes effective feedback practices in relation to AMS in elite

sport, but in the interim, advice from other disciplines may prove useful (Nicol & Macfarlane-Dick, 2006).

10.8 Other considerations

Technology and the AMS: help or hindrance?

Nuances: Technology can appear a panacea to many of the problems that typically beset AMS, such as poor adherence and data silos. The use of technology needs to be carefully thought through however, so it supports rather than detracts from the aims of an AMS.

Evidence: The majority of respondents (72%) in Chapter 4 used a mobile application to collect data for their AMS. Theoretically, this allows coaches, athletes and practitioners easier access to data for inspection and analysis, while allowing athletes to input their data at their convenience. Findings from this thesis, however, indicate that the user-experience needed to be nearly faultless in order to avoid end-users becoming disenfranchised with the online experience of their AMS (Chapters 6 & 7). Issues that were raised in the course of this thesis included: inaccessibility of historical data, forgotten passwords, cross-platform compatibility issues and the mobile applications failing to save data. When these issues occurred, they were typically associated with athletes reporting a drop in their AMS adherence. Findings from Chapter 7 also indicated that using a mobile phone to input their data often led to athletes becoming distracted, with other applications competing for, and in some cases winning their attention. Further, the use of 'dashboards,' i.e. landing pages which give automated AMS feedback, were reportedly rarely used by practitioners to communicate information to coaches or athletes (Chapter 4).

To date, it appears that there is no research exploring if the use of technology improves adherence to AMS. Based on research in allied areas such as health, it is unclear if the use of mobile applications or internet-based data entry improves adherence. For example, improved adherence rates have been noted in patients reporting their chronic pain levels on mobile applications in comparison to pen and paper (Stone et al., 2003), however mixed mode (website and pen and paper) was found to be better than a postal survey (Zuidgeest et al., 2011). Therefore, until more research is available to explore the impact of AMS delivery modality on athlete adherence rates, technology should not be viewed as a definitive solution to poor athlete adherence.

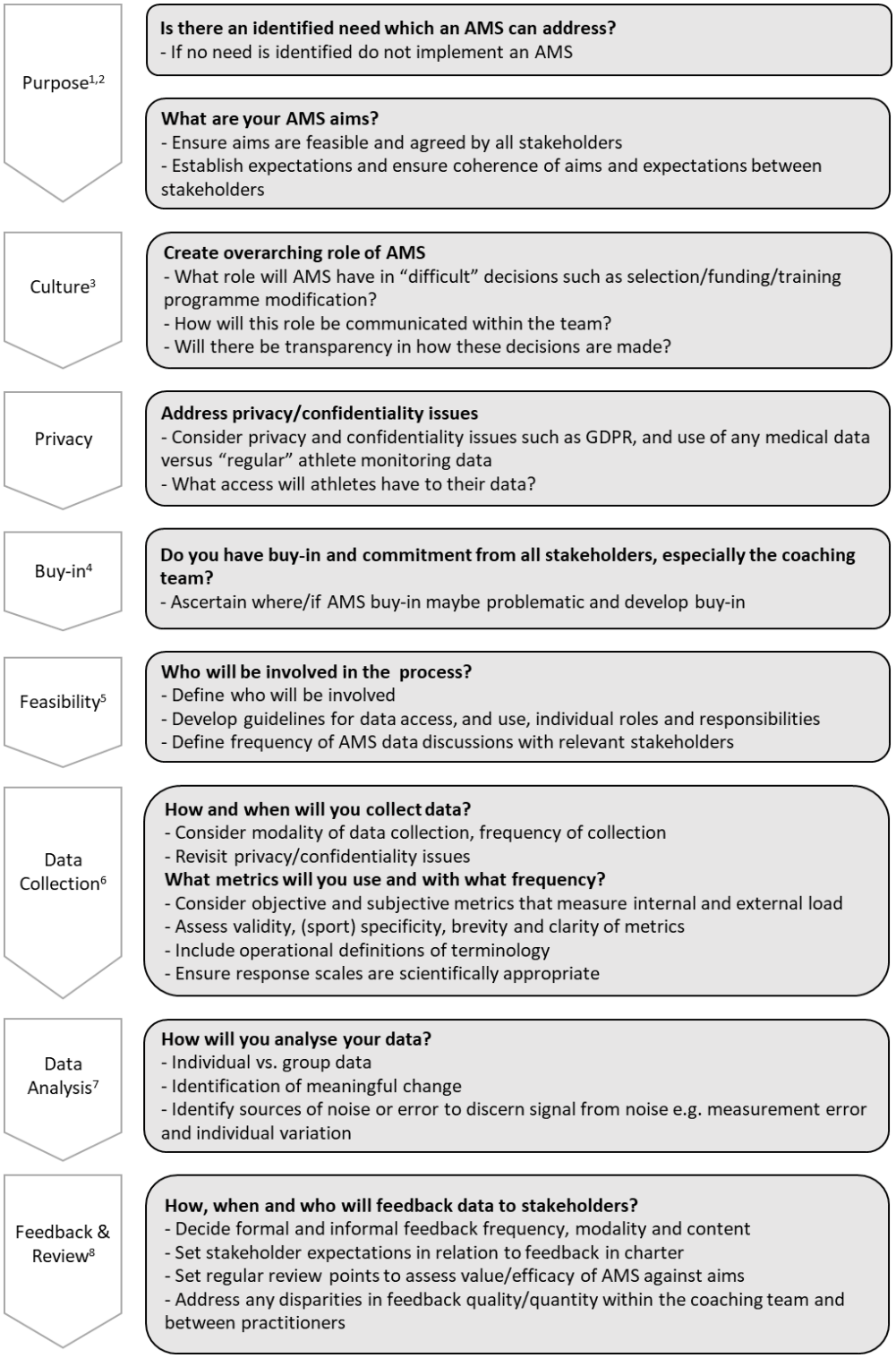

Figure 13. Adapted version of the steps to establish the purpose, stakeholder engagement and feasibility of implementing an AMS (Saw et al., 2017). Please see footnotes for resources to aid the identified stages.

[1]Needs analysis, e.g. SWOT (Gürel & Tat, 2017). [2]SMART objectives (Bjerke & Renger, 2017). [3]Consider a written agreement where the overarching role of the AMS and expectations are set out e.g. an AMS charter. [4]Behaviour change intervention with focus on coach-athlete dyad and feedback (Michie et al., 2014). [5]APEASE criteria (Michie et al., 2014). [6]For alternative validation techniques see Kyprianou et al. (2019) and Windt et al. (2018). [7]Data analysis resources: Atkinson et al. (2019), Gabbet et al. (2017), Hecksteden et al. (2015), Hopkins. (2000), Impellizzeri et al. (2020), H.R. Thornton et al. (2019), Sean Williams, West, et al. (2017). [8]Good feedback practices from premiership football, Nosek et al. (2020), and other disciplines (Nicol & Macfarlane-Dick, 2006) may help direct practitioners in this area.

11.0 Chapter Eleven - References

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12.0 Chapter Twelve - Appendices

12.1 Athlete Monitoring Survey for Chapters 4 & 5

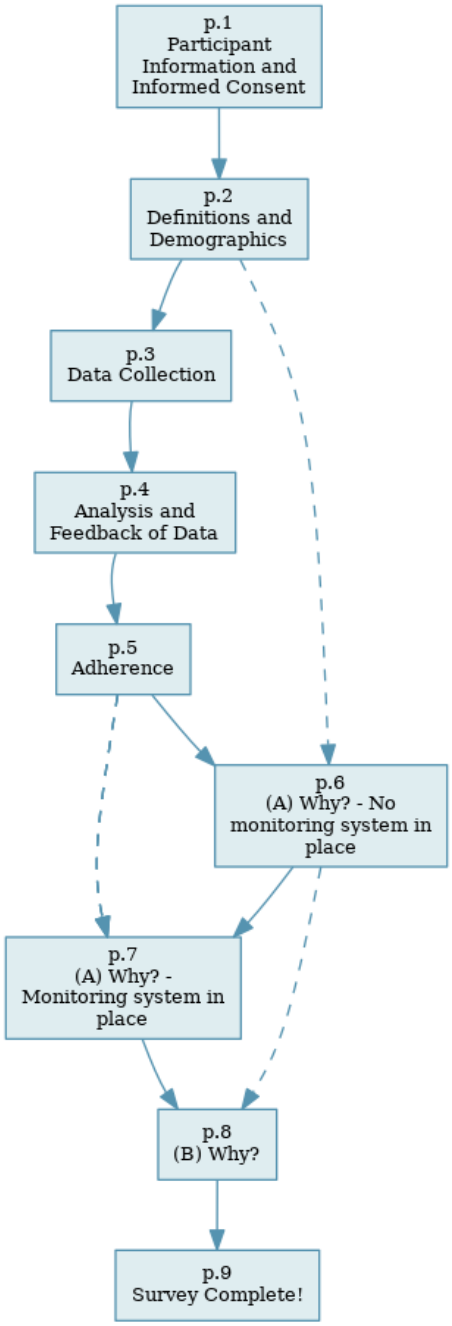

Figure 14. Map of survey flow (used in Chapter 4 and 5) with section titles displayed in each box.

Participant Information Sheet

Study Title: Training monitoring practices in high performance sport in the UK.

Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to check a box indicating consent before completing an online survey.

What is the research about?

The aims of the present study are to investigate what training monitoring methods are being used in high performance sport, how they are being implemented, and how they are analysed and subsequently fed back to those in the sport. The survey will focus on what subjective well-being measures are captured e.g. muscle soreness or fatigue but will also request information on objective measures that the sport uses e.g. hormonal assays. There will be an emphasis on ascertaining why the various training monitoring methods are used, and how that is perceived to make a difference to performance or training in the sport.

Why am I being asked to take part?

You are being asked to take part as you are a practitioner working in high performance sport and are likely involved with the administration of training monitoring in your sport. This survey is part of the EIS training monitoring working group.

What will I have to do if I take part and how will the information be used?

Taking part in this study will involve completing a brief online survey taking approximately 15 min which asks you to respond to questions about the training monitoring practices in your sport.

The results of this study may be published only if agreement is gained from the participants involved in the study. Any information published will not be linked to any specific sport, and identifying information will be removed. A copy of all your information, including results, will be given to you after completion of the survey, upon request.

Are there any benefits in my taking part?

Collectively, all information gathered will be of benefit to the training monitoring working group as it will allow for exploration of common themes and issues among sports.

Are there any risks involved?

In taking part in this online survey there is no risk greater than those risks faced in everyday life.

Will my participation be confidential?

We comply with the Data Protection Act and our own University policy on data management and storage. All information will remain confidential as no participant names will be attached to it. All data will be stored on a password protected computer only accessible to the researcher and their supervisor.

What happens if I change my mind?

You have the right to withdraw at any time without your legal rights being affected. There is no penalty for withdrawing and there will be no ill feeling.

What happens if something goes wrong?

In the unlikely case of concern or complaint, you should contact the chair of our ethics committee, Dr James Faulkner (email james.faulkner@winchester.ac.uk).

Where can I get more information?

If you would like to ask any questions about this research please get in touch with either *Emma Neupert or Prof. Simon Jobson*. Their contact details are below.

Researchers: Emma Neupert (University of Winchester) and Luke Gupta (English Institute of Sport).

Emma Neupert

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Informed Consent

Please check next to each box to indicate that you have read and understood the statement. Please find information on data protection by clicking the, "more info" icon below.

More info

	Required
	I understand and agree to the following statements
I confirm that I have read and understand the information sheet for the above study and that I have had an opportunity to ask questions.	☐
I understand that my participation is voluntary and that I am free to withdraw at any time without my legal rights being affected	☐

I agree to take part in the above study. *(Please select your response below) Required*

○ Yes ○ No

Definitions and Demographics

For the purposes of this survey please note the following definitions:

Analysis: The process by which wellbeing data is examined and/or statistically manipulated to determine meaningful change.

Feedback: The process of discussing results from the monitoring (wellbeing monitoring in this instance) with the multi-disciplinary team/athlete.

Monitoring: The collection of data about an athlete or the sport in general.

Sensitivity: The ability of a measure to correctly identify meaningful change. i.e. The ability of a self-report question to correctly detect a meaningful change in the athlete's wellbeing.

Wellbeing: A state of being comfortable, healthy and happy. In sport positive athlete wellbeing is usually associated with a reduction in lost training days due to illness/injury.

1. What sport are you working with? If you work with multiple sports please pick the one that you work with the most/have the most knowledge of. *Required*

2. How many podium level athletes do you work with? (*Please write the number below.) Required*

3. How many years have you worked in high performance sport? *(This could include amateur/professional sport or time spent working with development athletes that received funding. Please round to the nearest year). Required*

4. Do you have an athlete wellbeing monitoring system in place in your sport? For the purposes of this survey, a wellbeing monitoring system is defined as the sport collecting data on individual athlete wellbeing. Examples could include athlete self-report on their health and wellness, or collection of physiological parameters etc. Where athletes are under the care of medical practitioners, their medical records and exams are assumed to form the foundation of wellbeing monitoring. *Required*

- Yes
- No

Data Collection

5. Did you (and your sport) have a clear strategy for rolling out the wellbeing monitoring system? *eg planned athlete/coach workshops, clear feedback practices, articulated athlete expectations etc? Required*

More info

- Yes
- No
- Other If you selected Other, please specify:

7. Was the strategy underpinned by a scientific theory? e.g. Behaviour change, change management, nudge theory etc?

- Yes
- No
- Unsure

7. Did you feel you had support (from those outlined below) to roll out **and** ensure the wellbeing monitoring system was an ongoing success? *Required*

Please don't select more than 1 answer(s) per row. Please select at least 4 answer(s).

	No support	Partial support	Full support	Not applicable
Coaching staff	☐	☐	☐	☐
Managers in the sport	☐	☐	☐	☐
Fellow practitioners	☐	☐	☐	☐
Provider of the wellbeing monitoring system	☐	☐	☐	☐

8. Who collects the athlete wellbeing monitoring information in your sport? *(Please check all boxes that apply). Required*

Please select at least 1 answer(s).

- ☐ Athlete
- ☐ Coach
- ☐ Doctor
- ☐ Nutritionist
- ☐ Physiologist
- ☐ Physiotherapist
- ☐ Performance Analyst
- ☐ Performance Lifestyle
- ☐ Psychologist
- ☐ Soft Tissue Therapist
- ☐ Strength & Conditioning Coach
- ☐ Other If you selected Other, please specify:

9. What types of athlete monitoring data does your sport collect? (*Please check all boxes that apply). Required*

- ☐ Athlete self-report questionnaires e.g. wellbeing
- ☐ Blood profiling
- ☐ Cardiovascular parameters (e.g. morning heart rate)
- ☐ Gym loading data
- ☐ Hormonal profiling
- ☐ Performance tests
- ☐ Performance tracking during normal training
- ☐ Other If you selected Other, please specify:

10 a.. What tool(s) are you currently using to collect your wellbeing data? *(If you use more than one method please tick all boxes that apply)*

- ☐ Custom tool built for the sport
- ☐ DALDA Questionnaire
- ☐ POMS Questionnaire (either long or short version)
- ☐ PDMS/AER
- ☐ Rest-Q Questionnaires
- ☐ Smartabase
- ☐ Other If you selected Other, please specify:

10 b. What topics do you ask the athletes to self-report on? (*Please tick all applicable boxes, if there are other items not on the list please add them in the Other section) Required*

- ☐ Appetite
- ☐ Availability to train
- ☐ Dizziness
- ☐ Ease to fall asleep
- ☐ Energy level
- ☐ Fatigue
- ☐ Freshness
- ☐ Health
- ☐ Illness/Injury
- ☐ Irritability
- ☐ Modality of exercise session undertaken
- ☐ Mood
- ☐ Motivation (to train)
- ☐ Muscle soreness
- ☐ Overall feeling
- ☐ Shape
- ☐ Sleep hours
- ☐ Sleep quality
- ☐ Stress
- ☐ Session RPE (Rating of Perceived Exertion)
- ☐ Session duration
- ☐ Other If you selected Other, please specify:
- ☐ Unsure

10 c. Are Likert scales the primary method athletes utilise to rate their wellbeing? (*Please select one of the below). Required*

- ○ Yes
- ○ No
- ○ Unsure

10 d. Generally, how many points are there on your Likert scale? (*e.g. If you are using a 1 - 10 point Likert scale write 10 below).*

10 e. Do you know why this number of points on the scale has been chosen? *(Please briefly describe below, if you are unsure please just indicate that).*

10 f. What scale(s) are you therefore using for athlete self-report on wellbeing? (*Please use the free text box below to indicate how your athletes rate their wellbeing in lieu of using Likert scales.)*

10 g. Do your self-report questions indicate a time period for when athletes should report their wellbeing? (*e.g. What is your mood like now/yesterday/this morning). Required*

- ○ Yes
- ○ No
- ○ Unsure

11 a. How do the athletes record the majority of their self-report wellbeing data? (*Please select one of the following). Required*

Computer (e.g. directly into Excel)
Mobile device application (e.g. ipad, mobile phone)
Pen and paper
Other If you selected Other, please specify:
Unsure

11 b. Generally, how often do you/the sport require athletes to complete their self-report wellbeing monitoring data?

Daily
Weekly
Fortnightly
Monthly
Seasonally
Biannually
Annually
It varies (e.g. at certain time periods only)
Other If you selected Other, please specify:
Unsure

11 c. If it varies when you/the sport collect your wellbeing monitoring data, when, generally do you collect it?

- [ ] During camps only
- [ ] During competition times only
- [ ] During normal training only
- [ ] Other If you selected Other, please specify:

11 d. For medical practitioners - approximately how often do you see athletes in your care for routine check-ups? *(Please use free text below, we appreciate this may vary if they are unwell). Please pass on this question or write N/A if it does not apply to you.*

Analysis and Feedback of Data

Analysis

~ The process by which wellbeing data is examined and/or statistically manipulated to determine meaningful change.

12. Is there a standard or typical analysis method applied to the wellbeing data in your sport? i.e. once the data is collected it is normally analysed in a certain way?(*Please select one of the following). Required*

- ○ Yes
- ○ No
- ○ Unsure

13. What is the primary method you use to analyse athlete wellbeing data? *(Please select one from the following options).*

- Change scores
- Percentages
- Ratios
- Raw scores
- Rolling averages
- Rolling averages (with exponential weighting)
- Other If you selected Other, please specify:
- Unsure

14. You have indicated there is no standard analysis method applied to the wellbeing data in your sport. Please briefly explain why this is the case.

15. Generally, what criteria or statistics are used in your sport to assess meaningful change in the athlete wellbeing data? (*Please select one of the following). Required*

- Effect size
- No defined criteria
- Raw scores
- Standard Deviation
- Smallest worthwhile change
- I don't know
- Other If you selected Other, please specify:
- Unsure

Sensitivity: The ability of a measure to correctly identify meaningful change. i.e. The ability of a self-report question to correctly detect a meaningful change in the athlete's wellbeing.

16. How confident are you in the sensitivity of your wellbeing measures? (*Please check one of the following and refer to the definition above). Required*

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

Please don't select more than 1 answer(s) in any single column.

	Really not confident	Not confident	Unsure	Quite confident	Very confident
Confidence level	☐	☐	☐	☐	☐

If you lack confidence or are unsure about the sensitivity of your wellbeing measures, please briefly explain why.

What could be done to improve your confidence in the wellbeing measures? *(Please briefly explain below)*

17. *Please rate your agreement with the following statement:* **Scientific studies (from within the sport or the literature) underpin the use of my sport's general athlete wellbeing monitoring.**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Scientific studies (from within the sport or the literature) underpin the use of my sport's athlete self-report questionnaire.	☐	☐	☐	☐	☐

18 a. *Please rate how strongly you agree with the following statement:* **Are athletes removed from, or perform modified training as a result of meaningful changes in their wellbeing scores?** *Required*

	Strongly disagree	Disagree	Undecided	Agree	Strongly Agree
Athletes are removed from, or perform modified training as a result of meaningful changes in their wellbeing scores.	☐	☐	☐	☐	☐

18 b. If you disagreed with the statement - *"Athletes are removed from, or perform modified training as a result of meaningful changes in their wellbeing scores."* **Why do you feel these changes are not implemented?** (*Please use free text box below to give a brief explanation).*

Feedback

~ *The process of discussing results from the monitoring (wellbeing monitoring in this instance) with the multi-disciplinary team/athlete.*

19. Do you feel the athletes receive sufficient feedback from the wellbeing monitoring information they complete? *(Please tick one box below). Required*

	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Do you feel the athletes receive sufficient feedback from the wellbeing monitoring information they complete?	☐	☐	☐	☐	☐

20 a. Is there a feedback process (formal or informal) using the wellbeing data in your sport? (*Please select one of the following). Required*

- ○ Yes
- ○ No
- ○ Unsure

20 b.You have indicated that there is no recognised process (formal or informal) in your sport to feedback athlete wellbeing data. Please briefly explain why you feel this is.

20 c. What is the primary method used to discuss wellbeing data with athletes? *(Please select one of the following).*

Dashboard on mobile device
Email
Face to face discussion (group)
Face to face discussion (individual)
Presentation
Written reports
Other If you selected Other, please specify:
Unsure

Multi-disciplinary team: Members of the sports science and sports medicine team

21. Please indicate below how frequently the wellbeing data is generally discussed. (*Please select one of the following). Required*

	Never	Daily	Weekly	Fortnightly	Monthly	Biannually	Annually
Discussed with the athlete	☐	☐	☐	☐	☐	☐	☐
Discussed with the coach	☐	☐	☐	☐	☐	☐	☐
Discussed with members of the multi-disciplinary team	☐	☐	☐	☐	☐	☐	☐

Adherence

22. Please rate the following statement. Required

	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Athletes have had sufficient education on wellbeing monitoring and its importance.	☐	☐	☐	☐	☐
Coaches have had sufficient education on wellbeing monitoring and its importance.	☐	☐	☐	☐	☐

23 a. . Please rate the following statement. **Generally how often do the athletes complete their self-report wellbeing monitoring in comparison to expectation?** *Required*

	Unsure	Never	Rarely	Occasionally	Very frequently	Always
Completion frequency	☐	☐	☐	☐	☐	☐

If athletes did not complete their self-report wellbeing monitoring, do you think performance would be compromised as a result? *Required*

- Yes
- No
- Unsure

23 b. How do you feel athlete adherence to completing their wellbeing monitoring could be improved? *(Please briefly describe your thoughts on how these improvements could be made). Required*

24 a. Are there times in the training year where adherence to wellbeing monitoring is worse than usual? Don't count periods where wellbeing monitoring is not formally required e.g. after the season has ended. *(Please select one of the following). Required*

- Yes
- No
- Unsure

24 b. Please indicate the time(s) of the training year where you see this decrease in adherence. *Please check one or more of the boxes below as relevant.*

- During camps
- During competitions
- During illness/injury
- During normal training (when fit and healthy)
- Other If you selected Other, please specify:

25. Please indicate how much you agree with the following statement. **Athletes complete their self-report wellbeing monitoring honestly.** *Required*

	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Athletes complete their wellbeing monitoring honestly.					

26. If you felt athletes do not complete their wellbeing monitoring honestly, what do you think the main influencing factors are? (*Please rate the items below).*

	Never	Sometimes	Often
Influenced by fellow athlete expectations	☐	☐	☐
Influenced by coach expectations	☐	☐	☐
Influenced by support staff expectations	☐	☐	☐
Influenced by friends/family expectations	☐	☐	☐
Athlete concern regarding potential training consequences e.g. removal from training	☐	☐	☐
Athlete indifference or lack of engagement with monitoring	☐	☐	☐

27. Are there consequences when athletes do not complete their wellbeing monitoring? e.g. removal of privileges, changes to funding e.t.c. *(Please select one of the following). Required*

- ○ Yes
- ○ No
- ○ Unsure

If yes please give a brief description of what these consequences are.

28. Generally, do you think athletes feel that wellbeing monitoring is a burden on their time? *Required*

- ○ Yes
- ○ No
- ○ I don't know

29. (A) Why? - No monitoring system in place

Does your sport have a clear rationale for NOT collecting athlete wellbeing data? *Required*

- ○ Check this box to proceed to next question

Please briefly indicate whether there is a reason or rationale for not collecting monitoring data.

30. (A) Why? - Monitoring system in place

Does your sport have a clear rationale for collecting athlete wellbeing data? *Required*

- Yes
- No
- Unsure

31. What is the primary reason for collecting wellbeing data? *Required*

- Reduce injuries/illness
- Maintain/optimise performance
- Prevent over-training
- Monitor the effectiveness of a training programme
- Other

If you selected Other, please specify:

32. If you don't feel there is a clear rationale for collecting the wellbeing monitoring data please briefly explain why.

(B) Why?

33. Please rate the extent to which you agree with the following statement. **Athlete wellbeing monitoring in my sport needs improvement.**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Athlete wellbeing monitoring in my sport needs improvement.	☐	☐	☐	☐	☐

34. Please briefly explain how you think athlete wellbeing monitoring could be improved in your sport. *Optional*

35. Are there examples in your sport of internationally successful athletes that do not complete the training monitoring required by your sport? *Internationally successful = Podiums at major events eg World Champs/Cups/ OG etc Required*

- Yes
- No
- Not applicable
- Other If you selected Other, please specify: *e.g. You may work with a successful athlete who completes their own monitoring rather than the sport required monitoring.*

36. Is there anything else you would like to know more about in relation to athlete wellbeing monitoring? Or any other comments you may have?

Survey Complete!

Thank you for your time to complete this survey. The responses will be analysed and discussed with you as part of the training monitoring working group in due course.

12.2 Likert questions for Chapter 6

Please rate and circle the extent to which you agree with the following questions:

1. I feel I have received sufficient support and education to enable me to understand the reasons for training/wellbeing monitoring

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

2. Training/wellbeing monitoring and feedback has helped improve my understanding of my wellbeing.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

3. The questions posed in training/wellbeing monitoring are sensitive to changes in my wellbeing.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

4. I can identify a meaningful change in my training/wellbeing scores.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

5. When there are meaningful changes in my training/wellbeing scores (as determined by either myself or my coach/multi-disciplinary team) action is taken e.g. performing modified training.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

6. I respond honestly to training/wellbeing monitoring questions.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

7. Training/wellbeing monitoring and feedback helps optimise my training and performances.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

8. I receive sufficient feedback from the data I enter into training/wellbeing monitoring forms. (Feedback could be in any form, such as a presentation, discussion, dashboard on the monitoring app etc.)

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

9. Completing training/wellbeing monitoring is a burden on my time.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

10. I will continue to use some form of self-monitoring tool in the future.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

12.3 Interview Guides

12.3.1 Interview Guide for Chapter 6

1. What is your definition of athlete wellbeing?
    a. How can wellbeing affect your ability to train/perform?
2. Why do you think you are being asked to complete AMS?
3. What expectations of AMS did you have?
4. Do you think the AMS has helped your training and performances?
5. Do you feel the AMS questions we are asking are sensitive to changes in your wellbeing?
6. Do you feel you answer the AMS questions honestly?
7. What questions do you think we could include to better understand and monitor your training status?
8. Do you feel you received enough information and feedback from the data you entered?
    a. How would you prefer to receive feedback? (what format, frequency etc)
9. Do you think you would be removed, or perform modified training as a result of red flags or meaningful changes in your wellbeing data?
10. Did you consistently fill in the AMS during the last season? (Yes/No)
    a. Where there certain days or time-points where you stopped completing the AMS?
11. Are there consequences when your AMS is not completed?
12. What were the drawbacks (if any) of using the AMS?
13. What recommendations do you have for improvement of the AMS in the future?
14. Would you like to continue to use some form of self-monitoring tool?
15. Are you doing any additional monitoring outside of training/wellbeing monitoring?
    a. What additional monitoring are you doing? (If any)

12.3.2 Interview Guide for Chapter 7

The interview guide below was used in Chapter 7. In the post-intervention interviews some topics covered in the pre-intervention interviews were revisited.

1. What is your rationale behind the monitoring system?
2. What expectations of training/wellbeing monitoring did you have?
3. Do you feel the AMS is contributing to performance?
4. Did you have a strategy for roll-out of the AMS? (Coach)
5. Do you feel you have buy-in from the athletes/coaches?
    a. What is athlete/coach adherence to AM usage like?
6. What is and isn't working well in your AMS at the moment?
7. Do you think you/the athletes are truthful when they complete their AMS?
8. How does the data you collect transfer onto the mat?
9. Are meaningful changes in AMS data acted upon?
10. How often/do athletes/you get feed back from the AMS data?
11. Are there consequences when AMS data is not completed?
12. What recommendations do you have for improvement of the AMS in the future?
13. Is there anything else you would like to add?

Post-intervention interviews:

1. What do you think has changed since we last spoke?
2. Have you notice any improvements/decrements in adherence?
3. Did you manage to implement the behaviour change targets we discussed? (Coach)
    a. If so, how did they work out? – List and discuss
4. Were there any problems you noticed with the intervention/targets?
    a. If so, please expand?
5. Do you feel adherence has improved as a consequence of the intervention?
6. Do you feel the coaches/athletes have all bought-into the process of athlete monitoring?
7. Have you got anything else you would like to add?

12.4 Chapter 7: Extra Documentation Relating to use of the Behaviour Change Intervention

Step 6: Identify Policy Categories

Table 11. Policy categories were then matched to intervention functions

Intervention Function	Policy Category	Meets APEASE criteria?
Education	Regulation	Yes
	Service provision	Yes
Persuasion	Regulation	Yes
	Guidelines	Yes
Incentivisation	Regulation	Yes
	Environmental/social planning	Yes
Coercion	Regulation	Yes
Training	Regulation	Yes
	Service provision	Yes
Environmental restructuring	Regulation	Yes
Enablement	Environmental/social planning	Yes

Step 7: Identify Behaviour Change Techniques

Table 12. A series of behaviour change techniques were selected in relation to the individual behaviour change functions identified.

Intervention Function	Behaviour Change Technique	Meets APEASE criteria?
Education	Information about social, environmental and health consequences	Yes
	Feedback on behaviour and outcome(s) of behaviour	Yes
	Prompts/cues	Yes
	Self-monitoring of behaviour and behaviour outcome(s)	Yes
	Information about others' approval	Yes
Persuasion	Information about social, environmental and health consequences	Yes
	Feedback on behaviour/outcomes of behaviour	Yes
Incentivisation	Feedback on behaviour/outcomes of behaviour	Yes
	Monitoring of behaviour/outcomes of behaviour by others (no evidence of feedback)	Yes
	Self-monitoring of behaviour	Yes
	Social reward	Yes
Coercion	Feedback on behaviour/outcomes of behaviour	Yes
	Monitoring of behaviour/outcomes of behaviour by others (no evidence of feedback)	Yes
	Self-monitoring of behaviour	Yes
	Punishment	Yes
	Remove access to the reward	Yes
Training	Demonstration and instruction on how to perform a behaviour	Yes
	Feedback on behaviour/outcomes of behaviour	Yes
	Self- monitoring of behaviour	Yes
Environmental restructuring	Restructuring the physical environment (timetable) to allow case conferencing	Yes
	Prompts/cues	Yes
	Add objects (ipad) to the environment	Yes
Enablement	Social support (behavioural and practical)	Yes
	Goal setting (behaviour and outcomes)	Yes
	Self-monitoring of behaviours	Yes
	Review behaviour and outcomes goals	Yes
	Identity associated with changed behaviour	Yes