Can recorded data from elite athlete monitoring systems be used to improve athlete abilities during training and create injury prevention regimes?

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Declaration

I declare that the work described in this dissertation is, except where otherwise stated, entirely my own work, and has not been submitted as an exercise for a degree at this or any other university.

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TABLE OF CONTENTS

CHAPTER PAGE

RAMI PRESENTATION.......... i
PLAGIARISM DECLARATION.......... ii
PERMISSION TO LEND AND/OR COPY.......... iii
TABLE OF CONTENTS.......... iv
ABSTRACT vi
ACKNOWLEDGMENTS.......... vii
LIST OF TABLES.......... viii
LIST OF FIGURES.......... ix
GLOSSARY.......... x

CHAPTERS

CHAPTER 1 – Introduction.......... 1

CHAPTER 2 – Literature Review.......... 4
- Introduction..........4
- Review of Literary Articles..........6
- Implications for Further Research..........18
- Conclusion on Literature Review..........20

CHAPTER 3 – Methodology - Primary Researche.......... 21
- Industry Expert Interviews..........21
- Introduction to Data Recording Initiative..........36
- Athlete Monitoring Introduction and Results..........37
- Conclusion on Primary Research..........62

CHAPTER 4 – Closing Remarks.. 63
- Future Work...63
- Recommendation...65
- Final Conclusion..66

BIBLIOGRAPHY...68

APPENDICES

Appendix A – Questions for Industry Experts...71

Appendix B – Ethical Approval Final Submission ………...72

Appendix C – Final Athlete Monitoring Results ………………………......................................82

Abstract

This dissertation aims to review and analyse the data that is recorded and saved through wearable athlete devices in tandem with functional recordings to give an electronic full-body analysis of all participating athletes. This analysis will be completed by in-person analyses and recordings originating directly from the athletes. In addition, this dissertation includes a set of interviews with some of the industry's leading experts in this field of study.

The overall objective is to combine various methods of athlete profiling with a view to better data integration to best sculpt training regimes and prevent injury. This method has not previously been fully and comprehensively analysed in an accurate and readable format.

Data taken from elite athletes will be electronically analysed within two large Irish athlete development sporting bodies. In addition, athletes will be examined as to their functional movements and abilities, and any changes monitored. This information will be incorporated with the individual monitoring data for an overall evaluation of the athletes' abilities. The objective is to prove that the data taken from athletes throughout their exercise programmes contains information that can be utilised in training regime creation, long-term behavioural tracking and injury prevention.

To prove the effectiveness of this approach, current data held by those participating institutions will be reviewed and compared to specific athlete injuries or ailments. There will be a mix of athletes taking part in basic, weight, functional, injury recovery and prevention training. The data collected will identify the benefits of a "digital training regime" to athletes and their stakeholders.

Data will be recorded through wearable devices. Data recorded will produce a comprehensive and tailor-made training programme for each individual athlete.

The final result of the dissertation will be the proposal for an electronic record of an athlete which can be used for the future career of the athlete for training, recovery from injury, tracking of past injuries and long term analysis.

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LIST OF TABLES

Tables:

Table 1.0 – Industry Expert Breakdown 22

Table 2.0 – Industry Expert Involvement in Athlete Monitoring Systems............................... 24

Table 3.0 – Introduction to Measuring Techniques……….. 38

Table 4.0 – Introduction to Wearable and Monitoring Devices.. 39

Table 5.0 – User Interface Colour Coding.. 60

LIST OF FIGURES

Figures:

Figure 1.0 – User Interface Example 60

GLOSSARY

1. **RSImod** is a similar calculation to the reactive strength index: jump height divided by take-off time. **RSImod** can also be calculated from different vertical jumps other than just a depth jump

2. **Athlete Monitoring** is a term used for the tracking of an athlete's physical abilities and specifications. In this instance, it describes monitoring an athlete through a digital medium.

3. **Digital Recording** is the actual recording of a piece of athlete data related to a specific athlete.

4. **Functional Recordings** are the physical recordings taken from athletes that are not recorded through a wearable device but by a human. These will include such things as shoulder lift off, glute bridge etc. that must be viewed and entered manually.

5. **Wearable Devices** are pieces of technological recording equipment that automatically record and store various athlete information. These would include, heart rate monitors etc.

6. **Fitness** can be defined as a person being physically fit and healthy. **Fitness,** in elite sports, is the ability to be of a higher fitness level than an amateur athlete in that specific field, thus being of a higher class of athlete.

7. **Strength,** being similar to fitness in this setting, can be defined as a person's quality or state of their physical strength. Again, with reference to elite athletes, the strength of an athlete can vary massively between athletes but be suitable to their particular sporting endeavour.

8. The **Firstbeat System** is a form of analysis technology that provides its user with comprehensive data regarding an athlete's current state based on heartbeat measurement.

9. The **VX Sport** system is a GPS tracking system used by elite performance coaches. It aids with decision making while tracking an athletes performance and abilities. This information is then stored and can be used for further analysis such as injury rehabilitation after an injury occurs.

Chapter 1 - Introduction

This dissertation topic aims to create an elite athlete monitoring system that is comprehensive, user-friendly and affordable for all. In order to develop this system, data obtained through wearable athlete devices and functional recordings will be reviewed and analysed. Functional recordings will be carried out in person during the athlete's training sessions and recorded via a digital platform for use. The overall objective is to combine various methods of athlete profiling, with a view to better data integration, in order to best sculpt training regimes and prevent injury. This method has not previously been comprehensively analysed in an accurate and readable format. This dissertation sets out to prove that a transparent and measured athlete tracking system can be created.

In order to create and test this tracking system, data will be gathered from two main sources. First, primary research gathered from elite athletes will be analysed within two large Irish athlete development sporting bodies. Second, athletes will be examined as to their functional movements and abilities, and any changes monitored. This information will be incorporated with the individual monitoring data for an overall evaluation of the athletes' abilities. The objective is to prove that the data taken from athletes throughout their exercise programmes contains information that can utilised in training regime creation, long-term behavioural tracking and injury prevention.

Due to the variety of athletes in the modern sporting world, this research will be aimed across the board by pooling data from various sporting areas. The variety of athletes digitally tracked should provide comprehensive results capable of replication across a multitude of sporting disciplines. In addition, within these disciplines, players from different positions – with varying requirements in terms of strength and fitness, as well as susceptibility to injury – will be monitored to produce representative and varied data. For example, our analysis of rugby union athletes includes two forwards and two backs to demonstrate the wide application of digital tracking.

Monitoring athletes through a digital format is a relatively new phenomenon, but one which has become increasingly popular and will continue to grow. New technology in this area is constantly discovered. For example, a new system to measure the impact and effectiveness of an athlete is currently in the patent-pending stage. (Admir Dado Kantarevic, 2012). This technology could revolutionise the in-game analysis of individual athletes by giving a performance team the ability to optimise their athlete's real time abilities during a training or match play instance. This technology also has the ability to measure the force of an impact. This, for instance, could be used to pinpoint when an injury occurred based on measurements taken during match play.

This dissertation has a dual focus: (i) monitoring athletes' injuries and rehabilitation and (ii) monitoring athletes' functionality. Understanding the training and exercise regimes that best produce results in elite athletes is a major concern in the industry. This research will implement incremental functional analysis and comparison tools to define the success, in terms of an individual's athletic abilities, of a particular training regime. The functional analysis figures are easily recordable and once entered, can be stored for an infinite period of time and used by a wide variety of athlete stakeholders.

The primary aim of this dissertation is to prove that data recorded through wearable athlete devices can be used for long-term profiling once analysed, logged and stored correctly. Once this data is correctly entered into a specific storage system, an athlete stakeholder can use the data for a variety of purposes, including designing training regimes, preventing injuries and creating bespoke rehabilitation programmes. In addition, the tracking system will facilitate the athletes' stakeholders in their decision-making and strategizing. All athletes' data will be continuously updated in a readable format, thereby providing the stakeholders with an up-to-date transcript of the athletes' strengths and weaknesses. These readings can dramatically improve how a trainer sees an athlete's performance improve or deteriorate over a particular timeframe. For instance, one readable device utilised in this study can track an athlete's speed, strides taken and manoeuvrability over a predetermined distance. This information is highly valuable to coaches and managers in preparation for matches and competitions.

Chapter 2 of this dissertation provides a review of the literature in the field of elite athlete monitoring. Due to the fact that this area of research is a relatively new phenomenon, there is paucity of literature available. However, a number of analysis methods, and their reception in the academic community, are examined in order to provide a full overview of the topic.

The primary research carried out within this study is included in chapter 3. The primary research is divided between individual athlete recordings and expert interviews. Each athlete is briefly introduced before their recordings are listed and analysed.

The final section, chapter 4, delves into the potential for future work and an overall conclusion of the study. As there are no major studies similar to this dissertation, there is huge potential for further research to be undertaken in this field. The conclusion, finalises the points made throughout this dissertation and focuses on how the various research areas connected.

Chapter 2 - Literature Review

Introduction

a. Overview:

This dissertation topic will review and analyse data recorded and saved through wearable athlete devices. Data is extracted primarily in secondary form, from previous recordings, but also through primary, in-person analysis.

This dissertation aims to demonstrate that the data taken from athletes throughout their exercise programmes contains information that can utilised in training regime creation, long-term behavioural tracking and injury prevention.

Development, recording and analysis of the data collected will be completed through a digital monitoring platform to ensure reliability and transparency. The recordings and analyses will be categorised and made athlete-specific in order to arm the athlete's clinicians with the most relevant and appropriate data.

Most of the literature in this field of study focuses on the clinical aspect of elite athlete monitoring. However, in order to develop a comprehensive and pragmatic system model, scholarly articles on the technical aspects of such systems have been included. Some explain the methodologies behind monitoring athletes' abilities and ailments over a defined period of time whereas others give examples of the technologies available and how they can impact an athlete in both a positive and sometimes negative way. The mix of literature, both technological and clinical, gives the overall view of a positive consensus towards the acceptance of these systems.

b. Thesis Statement:

By combining various methods of athlete profiling, a transparent and measured athlete tracking system can be created in order to best sculpt training regimes and prevent injury. This model emphasises the nexus between the technical and clinical approaches to athlete development in producing quantitative proof of the benefits of digital monitoring.

c. Research Question

"Can recorded data from elite athlete monitoring systems be used to improve athlete abilities during training and create injury prevention regimes?"

Review of Literary Articles

1. How to Begin; Athlete Monitoring from Stage 1:

The technicalities of athlete monitoring have been widely discussed in academic literature. This study utilises two methods of monitoring; primary and secondary. The primary data is recorded directly from athletes as they are training, whilst the secondary data is previously recorded for comparison. Previously recorded data is reusable, assuming it is accurately recorded.

There are two core studies which are discussed throughout the contained literature review and are referenced substantially. The first (C.Glaros 2003) sets out the theory behind a digital training and injury prevention system, whilst the second (DJ Chambers 2002) shows what is needed for it to work successfully with regards to the contained data. However, DJ Chambers (2002) discusses that injury is in fact part of the game and although is predominantly inevitable, there are preventative measures.

Analysis Methods: Secondary Data

During an IEEE conference in 2003, one of the first wearable systems for monitoring an athlete's ongoing personal health was put forward (C.Glaros 2003). This device provided the athlete's medical team with a small amount of up-to-date information, readable through a decision support system. The system itself contained three main entities for use, most notably those wearable mechanisms for continuous monitoring. The continuous monitoring function, coupled with the "rehabilitation station" and user portal allowed an athlete's current condition to be monitored in real-time. This system can be credited with introducing to the international stage a monitor capable of aiding athletes and medical staff. However, by contrast to the system developed in this dissertation, this system was primarily used in injury rehabilitation and not with a view towards preventative measures.

Utilising real-time initiatives, when properly recorded and stored, could drastically help athletes achieve their short-term and long-term goals. Directly relating this article to one written by BJ Maron et al. (2008) will give an obvious correlation for the need of various in game athlete monitoring systems, such as the Vx Sport and Firstbeat technologies. Not only could they improve an athlete’s abilities and goals, but they could save a person’s life. For instance, BJ Maron et al have demonstrated that the absence of real time technology in athlete monitoring systems is directly correlated to issues arising from intense training or match play. In this study, BJ Maron et al discuss the deaths of a total of 1866 athletes over a 26 year period, the vast majority (1049) were due to cardiac arrest. Utilising modern technology, such as the Firstbeat system, could eradicate this from ever occurring again.

The system proposed by BJ Maron et al offers one approach to athlete monitoring through digital devices, and seems to be very similar to the Firstbeat system. However, the system is mostly based on the athlete’s present state during injury, and does not work towards a more effective and conclusive injury rehabilitation strategy. While the use of such a system would be beneficial to an athlete, a real-time initiative coupled with other monitoring practices would make a significant difference to athletes’ day-to-day activities.

Analysis Methods: Primary Data

When monitoring athletes through primary data collection, there are important considerations in terms of procedures for data collection, storage and use. Recent trends in the medical and sports industries indicate a preference for the collection of injury and illness surveillance data. Therefore, a large proportion of clinicians are looking for ways to record and analyse this data. However, as a paper published in the American College of Sports Medicine (Ian Shrier, 2014) emphasises, stored patient (athlete) data is only useful if it is collected and processed correctly and accurately. Shrier proposes three methods of achieving accurate data availability during collection, analysis, storage and transfer:

1. Data Entry

Ensuring that data is entered properly is of great importance. Shrier envisages three core ways to enter data for accurate analysis: *free text (narrative entry), formatted fields (multiple pre-defined entry options), and drop-down fields (specific entry options).*

2. Data Validity

The data entered must be of the highest quality. Quality must be ensured in both data entered automatically through various means and manually. It is recommended that protocols are put in place to ensure compliance with these standards.

3. Data Exporting

Exporting data to various different locations, be it to consultants or physiotherapists, can raise various issues with regards to data corruption or manipulation.

Entering quality data into athlete record systems is an important consideration that is often overlooked by some as unnecessary and time-consuming. The quality of data is of particular importance when data needs to be re-used at a future date. Protocols must be implemented to ensure correct data entry. While Shrier proposes general guidelines to be followed for data entry, these are not concrete and do not have the ability to span over different platforms. The guidelines themselves, portrayed in the previous paragraphs, are simple and usable but they are hindered by their inability to be used by numerous systems. For example, should a system require specific entry, it could not use free text entry as this could lead to incorrect entries. More research needs to be done to define what types of systems should use the particular entry methods.

In addition, if data is to be recycled, it must be stored properly. These days, modern storage systems are inexpensive, and should not pose an issue for many elite athletes. The information, once properly stored and categorized, could be kept for a potentially infinite period of time and be used numerous times to better serve the specific athlete and comparative athletes.

Injury Prevention

According to an article published in the British Medical Journal, many athletes believe that “injury is just part of the game”. (DJ Chambers 2002) While injuries are a reality of sporting endeavours, there is an abundant demand for research into standardization methods for the collection and analysis of data regarding injuries. If this data is processed correctly, it could be applied to mitigate, and even prevent, athletic injuries. However, the development of high quality sets of processes for long- and short-term injury prevention will require extensive collaboration from a wide range of sporting bodies.

BJ Maron and Shrier have recommended the inclusion of injury prevention regimes for elite athletes by collecting and storing data in a digital format during the athlete’s training and other sporting endeavours. They would be using a similar method to this dissertation, being a user interface connected to a spreadsheet or database backend. However, it is suggested that the most appropriate base method is the four step principle of the “sequence of prevention” model set out by Van Mechelen (DJ Chambers 2002). This model provides a structure for clinicians to use while examining the progress of an athlete at recovery or initial injury phase. The model is described below, as taken from Van Mechelan, 1992;

“Firstly the extent of the sports injury problem must be identified and described. Secondly the factors and mechanisms which play a part in the occurrence of sports injuries have to be identified. The third step is to introduce measures that are likely to reduce the future risk and/or severity of sports injuries. This measure should be based on the aetiological factors and the mechanism as identified in the second step. Finally the effect of the measures must be evaluated by repeating the first step. In this review some aspects of the first and second step of the sequence of prevention are discussed.”

Despite the validity of Chambers’ model, the athletes in that study did not demonstrate rehabilitation achievements past the initial stage of monitoring. This phenomenon is best explained by the over-emphasis on athletes’ serious injuries. Only targeting major injuries for prevention is not an ideal way to continuously monitor an athlete, as most serious injuries stem directly from minor injuries. Chambers’ model does not adequately address smaller, more progressive injuries which are far more prevalent in elite athletics. By contrast, using a digital athlete monitoring system could help track minor injuries and their overall severity, with the ability to help the athlete change their regime before the injury becomes more problematic.

2. Using Wearable and Recordable Intelligent Systems

In 2012 the Great British Olympic Track and Field Team ("**Team GB**") introduced a novel approach to dealing with athletic injuries. (HP Dijkstra 2014) Team GB adopted an "Integrated Health Management and Coaching" model (the "**IHMC model**") after coaches realised a pattern of athletes training despite injury or sickness. In the hopes of garnering this determination whilst mitigating the harmful results of over-training an injury, the model sets specific performance goals for recovering athletes. These goals could be as small as improving their 100m sprint time by .001 of a second. Alternatively, athletes could be tasked with much loftier goals, such as returning from injury two months earlier to compete at the Olympic Games.

Importantly, the IHMC model recognises the tension between the preferences of sports clinicians and athletes. The primary concern of sports clinicians is practising "safe medicine", prioritising rest at all costs. For example, when an athlete presents with a tight hamstring, many clinicians will order a complete cessation of training until the athlete fully recuperates. However, the athlete may believe they are competent to continue training and work on other aspects of their performance. In practice, the athlete's opinion is often irrelevant; but clinical research demonstrates that an athlete's self-rating of their performance abilities should be considered. Failure to include athletes in their training programmes can lead to a failure to disclose injuries for fear of being placed on rest. By including the athlete in the decision it is hoped that there will be a more honest approach towards injuries, benefiting both the individual athlete and their clinical team.

2.1 Using Wearable and Recordable Intelligent Systems: Multi-Purpose Functionality

A study conducted in East Tennessee State University (*CA Bailey et al. 2013)* explored the strength asymmetry of elite athletes in Baseball and Softball and its relationship to performance and injury. Strength asymmetry in athletes is viewed as a potential precursor for injuries in related areas. However, strength asymmetry has not been definitely proven to predict long-term injuries. Nevertheless, distribution of strength is imperative for elite athletes and can lower an athlete's chances of recurring injuries.

Measuring strength distribution in a digital format can provide athlete stakeholders with a transparent picture of any issues relating to strength asymmetry. Once an initial assessment has been completed, a specific training regime may be implemented over time to bring about symmetric strength. Improvements can easily be tracked after each assessment and compared to previous recordings, over time improving strength asymmetry and lowering the risk of further injuries. The clarity provided by a digital monitoring system will allow the athletes' stakeholders to alter training regimes to strengthen weaker areas and harmonise an athlete's distribution of strength. In gathering the relevant recordings, it is suggested that Shrier's (2014) input and output techniques be adapted. If the data is collected and stored in a high value method, it can be reused numerous times in different formats. For example, if one athlete becomes injured during training, this can be logged and red-flagged should another performance coach choose to use a similar training technique.

While the literature recognises the importance of strength asymmetry, it does not address how an athlete's strength distribution can be monitored and improved over a defined period of time. For example, using a system such as the one used in this dissertation, could provide adequate measurement for strength asymmetry. Giving each athlete a score of between 0-5 will show the asymmetry and the level in which it measures up, thus giving the athlete and their team direct knowledge of where improvement is needed.

3. Digital Monitoring: Making it Unique for Each Athlete

Suchomel highlights the need for varied athlete training regimes depending on their specific sport. (TJ Suchomel et al. 2014) Implementing a catchall training or exercise regime places the athlete at a major disadvantage. Tailored training, on the other hand, focuses on the athlete's specific improvement areas to the benefit of the individual athlete and his team.

The literature delves into developing specific muscular performance characteristics suited to each athlete's needs. Many characteristics differ between professional and amateur athletes, most notably their strength and endurance. These areas are crucial in elite athletics and need to be tailored for monitoring programmes. In addition, Suchomel (2014) found that muscle performance characteristics vary *within* team sports, i.e. different players/positions will have different requirements.

An RSImod (Reactive Strength Index) is a useful method for creating training and monitoring plans specifically aimed at an individual athlete. The RSImod is a calculation for determining an athletes force abilities: jump height divided by take-off time. RSImod can also be calculated from different vertical jumps other than just a depth jump**.** However, the RSImod is mostly a statistical based formula that may not fully align with an individual's injury history. This is a critical issue and could prove costly to the welfare of an athlete in medium- and long-term training programs.

The RSImod, coupled together with other sporting characteristics, is a valuable tool for analysing a specific athlete's strength requirement. However, its application should be limited as a starting point for athlete monitoring, such as a functional training index or injury prevention regime. As Suchomel's research demonstrates, data tracked through the RSImod method was highly useful for performance and training staff.

However, the biggest issue which this article lacks is diversity. This system, although working, only delves into certain areas which could prove costly. Suchomel fails to quantitatively prove the RSImod is an adequate long term method for athlete monitoring. The reason being that having great decision support systems in one area of performance training can lead to a lack of abilities in others.

4. When to Start Monitoring?

In the past, younger athletes played sports mostly for pleasure, fitness and to meet new people. However, there has been a dramatic change in recent times as many younger athletes are training at the same level and intensity as professional, elite athletes. Some coaches are even sending athletes as young as 14 to gyms to lift weights and gain muscles, before their bodies are even fully formed in many cases. However, young athletes still need to train and in many cases need to train harder due to their inclusion in sporting academies or junior world championships. If not done properly, introducing high intensity training for specific sports at a young age can be very dangerous to the athlete.

The physical and mental well-being of young athletes has occupied a precarious position over the last number of years. Large amounts of elite athletes are enduring fatal cardiac issues, from a very young age. BJ Maron (2008) carried out a study in the United States, which found that between 1980 and 2006 there were a total of 1866 deaths within the elite sporting community. The vast majority of these deaths were due to cardiovascular issues, while others resulted from dehydration and heat stroke. From the first year of this study, a steady rise of 6% in the number of deaths per annum was recorded. Out of all those deaths, 82% occurred during training or competition. Other causes of fatalities in this study were due to blunt trauma that caused structural damage (416 [22%]), commotio cordis (65 [3%]), and heat stroke (46 [2%]).

Again, these are very easily measured areas and could have been avoided if proper monitoring and care was undertaken with the athletes. A paper researching the advantages of Electrolyte Replacement Solutions by the Irish Sports Council (2014) could be seen as a viable way to aid in dehydration. This article describes the use of “Sweat and Electrolyte Composition” as a means of measuring dehydration. These recordings would show exactly what the levels of specific electrolytes (potassium, calcium etc.) are in an athlete and what they should aim to be.

Ensuring the health of young athletes demands a specific response to these issues. The Committee on Sports Medicine and Fitness (2000) proposes some varied approaches to managing young athlete health and development. In particular, the Committee emphasises guidelines for young adults in general. These guidelines are not tailored to a specific child or sport, and while they may work in the short term, they are not conducive to senior level athletics. In order to implement a safe and healthy training framework for young athletes, there needs to be a long-term focus. In response to the cardiovascular risks faced by young athletes, Maron et al suggest that all undergo ECGs during initial screening programmes. However, it is important to note that an ECG is not determinative of underlying heart functions.

The literature fails to recognise that electronic monitoring systems offer the best, and safest, approach to youth athletic development. At any age, an athlete can have their training, events and injuries monitored, recorded and stored. This data has the potential to reduce young athletes' risk of long-term injuries and prevent athletic fatalities. In modern-day professional sport, these electronic monitoring devices are widely used. The data gathered by these devices is constantly monitored in real-time by a trained professional, who in turn is overlooked by a team of athletic therapists.

While it may not be feasible to equip every athlete with a heart monitor during every activity in some sporting environments, monitoring 'high-risk' young athletes (based on their medical history) could be hugely beneficial. Additionally, tracking athletes' functionality from an early age is crucial in developing athletic abilities. Provided this information is properly catalogued, it will be available to athletes at all junctures in their career. The athlete's junior years can be accessed by future stakeholders to assess the athlete's capabilities and areas for improvement. In addition, monitoring such data would reduce the risk of long-term injuries, even once young athletes transition into higher levels of training and competition. In particular, a digital log of young athletes' cardiovascular patterns, hydration and body temperature will greatly reduce the number of cardiovascular incidents. (BJ Maron et al) There are currently 45 National Football League (NFL) players with serious heart conditions who play and train to the highest standard week in, week out. These players are able to train because their condition is professionally managed and monitored.

An article written by Richard Hinton (2012) points out that injury surveillance systems are a crucial aspect of the modern day competitive sporting world. Not only are they an integral cog in ensuring an elite athlete is equipped with everything they need to be more competitive, but they're vitally important to keeping them healthy and improving their overall wellbeing. This can also be linked directly to issues brought about by Dijkstra et al (2014) in the area long term health management of an athlete. Injury surveillance systems differ slightly from athlete monitoring systems as they are solely based on the rehabilitation of an injury and not on recordable data being processed. They also do not include other aspects such as training regimes, previous injuries and athlete statistics.

The big issue for many sporting organisations is the adoption of one of these digital monitoring techniques. Many sporting bodies, as discussed by Hanisch (2007), have a view that these monitoring tools are expensive and cumbersome. However, basic monitoring tools can be implemented at little expense. The digital monitoring technique used in this research, for instance, was developed using a simple spread-sheet system that incorporated a basic database.

5. Using Digital Monitoring Techniques

Hanisch views injury management as a determinative factor in achieving a competitive advantage in a sporting environment. Using strategic information systems, such as wearable devices, to improve athlete performances and prevent injuries can help put specific athletes ahead of their competitors. So, how do digital monitoring techniques work?

The main technologies used in digital monitoring for interaction with data are speech to text systems, manual data entry and human computer interaction. Speech to text based systems massively aid the speed in which data can be recorded by clinicians, whilst manual data entry is much slower. The advantage that manual data entry has over speech to text systems is that it is much more accurate. Speech based systems can often misinterpret what a user is saying and log incorrect readings, an issue that would occur far less in manual data entry systems.

Human Computer Interaction (HCI) is also discussed in this paper with regards to being presented in a readable format, this is essential for non-technical users of a computer based system to get the full use out of it. It would be a pointless endeavour to display raw or even semi raw data to a user who does not understand it. Utilising proper design methodologies is a key ingredient for any athlete management system, a topic which is not discussed in depth in this paper (Ian Shrier). The recorded data of an athlete needs to be presented in a user friendly format if there is any chance of the idea catching on and athlete stakeholders using it for essential analysis tasks. This would be linked directly to a proposal such as the one being put forward in this study which would be a simple, spreadsheet based analysis and recording tool that can be easily taught to any potential athlete stakeholder that would be using it.

6. Existing Systems

Injury Surveillance Systems (ISS) are a crucial tool for any elite athletes in modern day sport. ISSs are highly effective in clinical use for injury prevention and have the potential to change management actions. Further, ISSs drastically decrease the amount of financial and administrative tasks placed on athlete stakeholders during an injury period.

Currently, some data management tools are in wide circulation in the sporting world. The majority of these tools are used in the United States to keep track of athletes' current injuries. An example of an ISS coupled with a data management tool, InControl, is used within the NCAA (National Collegiate Athletic Association). The InControl system has been opened up to top-level high schools in the US to facilitate younger athletes, an idea that was discussed previously. This system is talked of as "state of the art", and implements proper data standards as recommended by Shrier (2014).

However, this system is only used for the analysis and tracking of current injuries. Current injuries are stored, but not incorporated into an athlete health record, meaning that the data cannot be re-used. Therefore, this is room for expansion within this model. If the NCAA is monitoring an athlete's injury over a given period of time, this data could be used for that athlete's long-term analysis, and even to help similar athletes. If a player can have their own personal athlete health record set up at a high school level, tracking their injuries, abilities and regimes undertaken this could be carried on into a collegiate setting and perhaps further into the professional arena.

In the long run, expanding and reusing a system such as the one in place in the NCAA could prove very effective for monitoring an athlete's injuries and even abilities across a medium and long term period of time. As previously discussed, this information could also be utilised by similar athletes, improving the efficiency of such a system.

In relation a previous article discussed by Glaros (2003), this would be the system that is closely linked to what an end goal should be. However, crucially, it lacks the reusability that could so easily be added and turn this existing system into a full athlete management and monitoring platform, similar to some of the characteristics used by the Great Britain Athletic Team (Dijkstra et al. 2014). By simply including new functionalities and incorporating the protocols set out by Ian Shrier (2014), this could be the most ideal elite athlete monitoring system that has a proven track record.

Implications for Further Research

Monitoring athletes through a digital format is a relatively new phenomenon, but one which has taken off and will continue to grow. The main area, which is being researched in this dissertation, is the constant monitoring of not only injuries and rehabilitation but also the inclusion of the exact training and exercise regimes each athlete is undergoing and how it affects them. This will be done using incremental functional analysis and comparison tools to define if a particular training regime is improving or hindering an athlete's abilities. These figures are easily recordable and once entered, can be stored for an infinite period of time and used by a wide variety of athlete stakeholders.

Reusability of data could be a key process moving forward. If every aspect of an athlete's physical attributes are accurately recorded and stored, they could be used for other similar athletes. This could prove to be a cost effective way of implementing personally tailored training and injury rehabilitation programmes to specific athletes with similar characteristics.

Starting these screening and analysis phases from a young age could potentially prove to be a huge advantage. Having a detailed track record of a specific athlete could be a determining factor for various issues in their future sporting career. For example, some injuries may be forgotten or even lied about by the particular athlete, this situation could lead to serious issues arising but with a detailed athlete health record available there will be a reduction in these incidences occurring.

Cardiovascular issues within athletes have always presented problems. Substantive research has been done on the deaths of athletes relating to heart conditions, as cited above, but little to assess how to constantly monitor these issues. Utilising modern technologies, for example wearable heart rate monitors, is the future of cardiovascular management in sport. These monitors can record and store valuable information regarding an athlete's ongoing heart condition. This would be especially significant to those athletes who are aware of their pre-existing conditions, but could also massively improve the management of every athlete that is being monitored. BJ Maron et al (1996) put forward the idea of a "Preparticipation Cardiovascular Screening" for competitive athletes. This process could be done at any age and could potentially save an athlete's life whilst even discovering heart conditions that were previously unknown to a specific athlete.

The main gap, in a very lucrative sector, appears to be in the area of a reusable, tailorable and athlete-centered digital health record for monitoring an individual's past, present and future activities with a view to better understanding each athlete as a unique entity. With this, comparable data will become available for better understanding the potential future pitfalls of a specific athlete.

Conclusion

There is conclusive proof within the articles reviewed above that monitoring athletes training and injury processes can provide a valuable competitive advantage. With this, however, there is still drastic room for improvement and upscaling. Currently no major sporting body encompasses the idea of tracking both training and injury practices for the purpose of regime analysis. This tool could prove to be of huge benefit for both the athlete and their stakeholders.

New technology in this area is being constantly discovered. For example, a new system to measure the impact and effectiveness of an athlete is currently in the patent pending stage (Admir Dado Kantarevic (2012)). This could revolutionise in game analysis of an individual athlete.

Having an athlete's full health history could be a vital inclusion to the abilities going forward. Gone are the days where a physiotherapist would ask "have you had any injuries there before?" they should be able to simply click a button and view every injury related to a particular athlete and what their rehabilitation programme was. Including training regimes for better understanding and long term tracking of an athlete will give a digital history of a particular athlete for any person who requires it.

Chapter 3: Methodology – Primary Research

Industry Expert Interviews

Introduction

There will be a total of 6 industry expert interviews included in this dissertation. The interview subjects were selected due to their knowledge of athlete monitoring systems. The variety of persons interviewed should provide a representative insight into the opinions of industry experts in the field of athlete monitoring. Each expert has previous experience with wearable devices, monitoring systems and direct athlete contact. The experts surveyed include:

- 2 x Athletic Therapists
- 2 x Sports Scientists
- 2 x Elite Athlete Coaches

All interviews are comprised of the same questions. The interviews are based on an eight-question, two-tiered survey which asks whether (i) the subject has encountered a topic and (ii) if so, their opinion on the topic in question. It is expected that answers will vary, even within disciplines. However, all information gathered, when coupled together, should provide a helpful analysis of how these systems are rated and used within the elite sporting world.

It is hoped that these interviews will produce important insight into digital athlete monitoring from a professional standpoint, and can supplement academic analysis and opinions of existing monitoring systems.

Questions for Industry Experts

Each industry expert will be asked a total of 8 questions. These questions are detailed, for convenience, in Appendix 1.

Answers received from industry experts will be analysed in both table and paragraph form. An overview of opinions and feedback according to areas of expertise will be provided thereafter.

Industry Expert Breakdown

The specific experts have been categorized below in accordance with their particular areas of expertise:

Athletic Therapists	Expert: 1	Expert: 2
Sport Scientists	Expert: 3	Expert: 4
Elite Athlete Coaches	Expert: 5	Expert: 6

Table 1.0

Analysis of Industry Expert Responses

Feedback received from industry experts will be analysed in two manners. First, each specific question and the answers which were cumulatively received from all participants will be analysed. This first tier of analysis should provide a detailed overview of expert opinion across subject areas.

The second tier of analysis will focus on the specific industry experts. Each group of experts' answers will be separated to show the correlation between their views and the industries in which they practice.

I. Cumulative Analysis

Question 1: ***Have you ever been involved in the development or use of an athlete monitoring system? Specifically used for the overall monitoring of an athlete. If yes, please provide a brief detail of the system.***

Out of the six industry experts surveyed, all had experience in the use and/or development of an athlete monitoring system, albeit in varying circumstances. For example, while one sports scientist helped develop a large National Football League (NFL) player management project, he does not directly use the final product due to his involvement in another sporting organisation. By contrast, another sports scientist was involved in the development of an athlete monitoring system used by large athlete monitoring company, and has experience in using the system directly with clients.

Monitoring an athlete through a digital medium requires varied knowledge, one interviewee points out. When asked about their personal experience of an athlete monitoring system, they speak about how an entire team is involved in the digital monitoring of an individual athlete, far different from the past when it would primarily have just been one person directly associated with the task.

Below is a table that shows which industry experts were involved in the development and/or use of digital athlete monitoring systems:

Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
Development and Use	Use	Development	Development and Use	Development and Use	Development and Use

Table 2.0

As shown in the table the majority of the industry experts were involved in both the development and use of at least one athlete monitoring system. This proves the theory that there is a requirement for varied knowledge when developing and using athlete monitoring systems.

Question 2: ***Do you believe that monitoring an athlete's physical attributes could improve their abilities and performance? Please give a short reason for your answer.***

The answers received in response to this question demonstrate an overwhelming opinion that athlete monitoring is hugely beneficial for the athlete, both physically and mentally. From a clinical standpoint, when asked about the possibility of athletes improving their abilities and performance, the interview subjects emphasised the multiplicity of benefits in monitoring an athlete’s health. Expert 5 asserts that monitoring athletes must be undertaken on an individual and unique basis in order to provide a meaningful contribution to athlete development.

Expert 3 discussed the inability to accurately record and store multiple recordings from different devices in the same system as a major roadblock to improving an athlete's abilities through digital recording. Expert 1 opined that the need to discover what is “normal” for a particular athlete could prove to be crucial in a successful management programme. Calibrating devices towards an athlete’s individual idiosyncrasies can be achieved by analysing his or her micro-changes, phenomena which can only be detected by computer-based systems.

The most interesting point brought up by this question related to the readability of data. Amongst the industry experts surveyed, there was an overwhelming idea that if athletes’ recorded data was easily viewable and accessible to anyone, it could prove to be a critical to training staff. This feedback cements the view asserted by Shrier (2014), the quality of and ability to access data is a core competency of any digital athlete system.

Question 3: ***Have you ever thought that an injury might happen but the athlete involved insisted on continuing, then the injury did occur? If yes, please give a short description of the occurrence.***

This question is aimed at producing a clinical perspective on the use of athlete monitoring systems to prevent injuries. Expert 2 recounted an instance where a wearable device, used by an athlete's physiotherapy team, detected an athlete's acute injury. The injury was discussed with the specific athlete and he was advised to enter rehabilitation protocol. The athlete did not follow these suggestions and exacerbated his injury. This outcome could have been prevented by using a comparison system to show the athlete what could happen if he continued to train, so that he could make an informed decision.

There were varying opinions on whether or not injuries can be predicted. The majority of experts interviewed believed in the prediction of injuries, to a certain extent. Expert 6 notes that if proper data is recorded, according to one expert, then an athlete's functional abilities and strength can be tracked over time and any changes flagged. If this procedure was fully implemented, over time a predictable scale for injuries in specific athletes could be developed. However, Expert 4 believes that the accurate prediction of injuries depends on the clinical and technical skills of those experts monitoring the athletes.

One of the most interesting points was using a "pre-hab" method; this can be used one on one with multiple athletes with an aim to developing a programme to better manage their wellbeing. The pre-hab method is a tailor made exercise programme that continually evolves with the athlete. It involves working on weaknesses that may cause injuries to the athlete. Expert 1 and 2 both cited this as a similar method for reducing the risk of injuries. Starting this method from a young age is advantageous, but can be implemented in similar fashion to the system described in this dissertation at any time.

Question 4: ***Could long term physical analysis of an athlete pose any issues in the present or future? Please give a short reason for your answer.***

Responses to this question demonstrated considerable consistency; all respondents quoted similar advantages and disadvantages of digital athlete monitoring systems. The biggest advantage of athlete monitoring systems is that if the data gathered is reliable, valid and sensitive to change then the long term physical analysis of athletes can only lead to improvements in individualised training prescription, improve injury rates and athlete performance.

The biggest disadvantage of such systems, however, are the commercial considerations of athlete monitoring systems. In relation to player negotiations, including contracts and transfers, obtaining a detailed history of individual athlete's ailments could prove costly to both the athlete and their financial stakeholders. If a player's injuries are on record, this could raise red flags when the player wishes to move to a new club and hinder their ability negotiate a higher salary.

Another potential pitfall is the accessibility of such systems and issues of data protection. Athlete monitoring systems contain sensitive personal information that needs to be protected by maintaining proper accessibility standards, such as those implemented in medical facilities worldwide.

Question 5: ***What is your opinion on an "Electronic Athlete Health Record" being available to all potential athlete stakeholders? This would contain relevant training, injury and rehabilitation regimes a specific athlete has undergone throughout their career.***

All experts interviewed expressed the opinion that the advantages of an Electronic Athlete Health Record ("**EAHR**") were potentially endless. The majority of experts responded that an EAHR would be an invaluable asset to performance teams and would greatly aid the athlete management process. However, all experts expressed concerns over data accessibility, and agreed that these records should be classed in the same category as medical records. Expert 2 emphasised that access should be limited to medical and coaching staff, while outsiders, including potential scouts, should be excluded.

Expert 5 raised an interesting concern over the transfer of data when an athlete moves clubs. First, the data could be compromised by a divergence in systems or the move itself. This issue would be eradicated by the use of simple data protocols that will enable seamless data transfer between different sporting organisations. These protocols, will set out exactly how all system users should operate and what formatting is required for data collection, storage and exporting.

Second, for reasons of commercial sensitivity or competitive strategy, the club may not release the athlete's data. Major sporting clubs expend large amounts of money on their athlete development and rehabilitation programmes. These clubs will not be keen to freely release the training programmes developed by their staff. Unfortunately, in elite athletics, competitive advantage takes priority over athlete well-being. In relation to elite athletes, one solution may lie in the re-negotiation of athletes' contracts to include a term to the effect that the athlete maintains ownership over their recorded data and merely licences that data to the club for the duration of their contract. Once the athlete moves to another club, the former club has no right to access the data. However, athlete monitoring systems are meant to operate on the basis of shared data to facilitate athletes suffering similar problems, and restricting access to this data operates counter to this ideal.

Question 6: ***Have you ever been involved in the use of electronic monitoring devices for athletes? Such as heart rate monitors, speed gates, respiration measurements etc. Please describe briefly if you have including your opinion of their use, advantages and disadvantages.***

The most commonly used electronic monitoring device that was presented during this investigation was a GPS system, widely used to track players' performance and training statistics during physical activities. Every interviewee, when prompted to speak about the various monitoring systems they have used, claimed to have used one of many different GPS monitoring systems. According to the industry experts, a number of these systems presented the same issue: the unreliability of results. In particular, Expert 2 found a 5% error rate in all GPS tracking systems after carrying out an audit on such systems in a previous season. Unfortunately, if these errors go undetected, they will often be stored in the system and corrupt an athlete's recordings. The unreliability of some of these systems can be attributed to the age of the respondents' models. While many of the older models are problematic, none of the highest grade GPS systems were reported by respondents to be unreliable.

Another common device used to monitor elite athletes is a heart rate monitor, which is commonly utilised in the elite sporting world. (BJ Maron et al, 1996) However, many experts point to a common issue in the unreliability of these devices. Expert 4 asserts that this issue could be addressed by properly recalibrating such devices to record unique readings for different athletes. This would be done through the tailoring of these devices depending on age, weight, specific sporting endeavour (weight training, marathon, international football match etc.). Doing this would ensure more accurate readings in relation to the particular athlete and the exact physical exercise they are participating in.

Question 7: ***Do you believe that electronic monitoring devices (such as heart rate analysis) should be used by all elite sporting bodies? This primarily being for player safety and data collection. Please give a short reason for your answer.***

High profile cases in the media such as Fabrice Muamba (BBC Sports Correspondent, 2012) and Radwan Hamed (James Orr, 2015) serve to highlight the need for electronic monitoring devices and the screening of athletes on a regular basis. When asked about the use of these devices, specifically heart rate monitors, Expert 1 spoke about how heart rate monitors have become obsolete due to cardiac screening through magnetic resonance imaging (MRIs). While MRIs are more accurate, they are not pragmatic primary resources due to their expense and lack of wide availability. Heart rate monitors are affordable (Christina Bonnington, 2015) and allow athlete stakeholders to have real-time recordings for each individual. MRIs may be used intermittently throughout the season to supplement these readings.

As expressed by three interview subjects, monitoring an athlete's heart rate on an ongoing basis could prove to be a key performance indicator whilst ensuring player welfare. As aforementioned, the primary concern is the reliability and validity of the data recorded. In many cases as stated by various experts, athlete stakeholders can predict cardiac or even fitness issues arising by simple heart rate monitors being used during physical activities.

Question 8: ***What is your overall opinion of a digital monitoring system being used to better track an elite athlete's training regimes, injuries and injury rehabilitation programmes? Please list any advantages and disadvantages you feel are relevant.***

This question was designed to gather an overall opinion across the entire industry. The consensus amongst those interviewed was that the determinative factor in the success of an athlete monitoring system would be the ability of athlete stakeholders to properly record, view and use data in a safe and secure environment. However, Expert 6 pointed out the practical issues in manually cataloguing and storing the vast amount of data that would be recorded by such systems.

Digital athlete monitoring systems allow an athlete's performance team to handle, report and track a large amount of data continuously produced by the athlete. These systems can be used by a wide variety of persons, including those without much technical knowledge. Giving non-technical users the access to a wide variety of new clinical decision support systems not only makes their job easier but gives them endless abilities to better track and treat their athletes. With this, there will often need to be some training for new users, as pointed out by Expert 5.

The core disadvantage is that no athlete monitoring system can replace many aspects of human interaction amongst athletes and the multi-disciplinary performance team. How the player interacts, moves, their body language and appearance are impossible to be monitored digitally without physical recording and these are key elements in the ongoing management of athletes. These characteristics, however, would only be secondary causes for injury, as pointed out by Expert 6. They are more to the issue of player welfare. Expert 6 gives more details about how he and his colleagues use a 1-10 measurement scale for their athletes during injury periods, this helps them to categorise the mental state of an athlete during rehabilitation.

II. <u>Industry-Specific Analysis</u>

A. Athletic Therapists:

Athletic therapists are crucial to an athlete's performance and recovery and are an integral part of their day-to-day life. Overall, the athletic therapists surveyed had positive feedback on athlete monitoring systems, but point to some issues in long-term analysis.

Both professionals noted that monitoring an elite athlete on a regular and ongoing basis is a vital asset in the modern competitive sporting world. Each interviewee presented cases where athletes' injuries were predicted by physical and digital analysis tools. Expert 1 expressed the challenges he faced in trying to deter competitive athletes from training when they were injury-prone.

Experts 1 and 2 only differed in their opinions on the use of heart rate monitors by elite sporting bodies. Expert 1 believed that heart rate monitors should constantly be used by all sporting bodies during all physical activity. Expert 2 preferred screening programmes at intermittent times throughout the season, so that only those at cardiac risk would wear the devices during strenuous activity. Both are valid arguments, but as the second expert states, if the sporting body has the money to pay for these monitors there is no reason they cannot be used.

The only disadvantage of athlete monitoring systems, as expressed by both Experts 1 and 2, is their inability to detect and monitor every aspect of an athlete's well-being. Although new devices to track an athlete's physical movements are in development (DARI Sports, 2015), those devices will always be limited in their application and cannot detect subtle signs of human physiology. Other disadvantages cited by the athletic therapists are in the areas of interoperability and transfer. Expert 2 failed to understand that these multiple systems (wearable device and functional recordings) could be brought together into the same system with a single user interface. Also, both therapists expressed that they would not wish their intellectual property (training and injury prevention regimes) to follow an athlete to a new sporting organisation.

Sports Scientists:

Both sports scientists involved in this research project have past and present experience in the creation and use of some of the most technologically-advanced athlete monitoring software in the world. Their views were an excellent comparison to both the coaches and athletic therapists as they were able to give expert opinions from a different angle, that being a wider picture of athlete monitoring initiatives, and not primarily first person analysis.

There were much different opinions, from the sports scientists, about the use of an electronic athlete health record. One posed the possibility that it could be “too idealistic” for use in professional sport. Constraints could be brought up by, for example, physio staff being against sharing training regimes or other intellectual property. The issue of transfers and wages was also highlighted. This could potentially be an issue for high level professional players, as discussed earlier, as it may decrease their ability to bargain for a better contract, transfer or wage increase due to the in depth data regarding their personal health.

The overall opinion seemed to be aimed more to the idea of a digital monitoring system being used as a sort of medical tool, thus giving valuable aid to the professionals. This is evidently what athlete monitoring systems are supposed to do in elite sporting environments much like a clinical decision support system (Eta Berner, 2009).

Experts 3 and 4 entirely support the idea of continuous athlete monitoring to ensure the best possible care and wellbeing protocols are undertaken. Again, citing a big potential downfall that improperly submitted and stored data can cause serious problems in the future. This is on the forefront of issues from the majority of interviewees and is a real world day to day problem for not only athlete monitoring systems, but for any medical based platform that requires any manual human input (RCR Admin, 2015)

Elite Athlete Coaches:

While both coaches agreed on the use and need for digital monitoring tools, their opinions differed in a number of respects. Expert 5 believed that digital athlete monitoring, at all levels, has the ability to improve athlete performance. However, Expert 6 put forward the notion that athlete monitoring merely produces data, which is useless without its interpretation by a trained and skilled professional. Both experts cited past issues of recordings that were unusable due to improper collection and storage procedures. This point is worth discussing. Much like a layperson viewing medical records in a doctor's office, much of the information produced by athlete monitoring systems will be completely intangible and will mean nothing to the average person. Therefore, it is of the utmost importance that all available data is in a readable platform that a non-technical athlete stakeholder can use. Referring back the Ian Shrier (2014) and his ideas of data processing, utilising protocols similar to the ones set out in his article could alleviate this issue from arising. Although his theory is more to do with data quality, it could be reused to ensure readable and accessible data is available to all.

Another point raised by the coaches was the appropriate time to start athlete monitoring. Expert 6 emphasised that the earlier these tools are used the better, as there will be far more data recorded over an athlete's playing career. This will enable far better analysing abilities for athlete stakeholders in the future by giving them a full working history of each specific athlete they are assigned to.

The primary concern of these experts was long-term athlete monitoring. For example, if a player switches teams there may be issues with how the new performance team records data. For instance, as said by Expert 6, if there is no universal way to record athlete data then it may be completely different and useless should an athlete switch teams and therefore coaching staff. Expert 6 suggested establishing a universally-used platform. However, as discussed, the establishment of such a platform may be difficult in an industry where competitive advantage is key.

Conclusion

There were some excellent points collected throughout this industry expert analysis. Many had been discussed in previous sections but have been cemented by the various interviewees.

The main benefits for athletes and users taken from this section are as follows:

- Comparative ability to assess rehabilitation protocols.

- Longitudinal understanding of the impact of motor development and neuro-motor development on player potential and/or injury incidence.

- Promoting transparency and effective monitoring for professional judgement and decision making for practitioners.

- Long term analysis of athletes can lead to better understanding of their individual needs.

With this, however, there were some potential pitfalls that were put forward:

- Proper use of the system must be ensured with regards to recording, storing, analysing and the transfer of data.

- Long term athlete monitoring could pose problems to player transfers and wage negotiations as there will be a full record of their entire playing career.

- Different sporting bodies may use different digital entities creating issues with athletes transferring.

Overall, there was a hugely positive response from this group of industry experts towards the idea of a digital monitoring system with all respondents having had some if not vast experience in similar systems making their opinions far better.

Introduction to Data Recording Initiative

The data that will be recorded during this study is directly from each specific athlete. The actual functional, stability and wearable device recordings has been selected by trained professionals from the two large athlete development organisations to tend to exactly what is needed. This has been coupled with the added touch of a prominent user interface and spreadsheet storage system which can be used for comparison and contrasting specific athletes or programmes.

Once recorded, the data will be stored in a spreadsheet as previously stated. This spreadsheet is directly linked to each athlete's personal profile and the data recorded can be reused to the system users wishes through a multipurpose interface. This, for instance, means that if a trainer wishes to use a successful injury rehabilitation programme they can do so be querying the database and selecting the specific programme they want. Doing so will show on a specifically built user interface the programme, previous milestones by other athletes, best case scenarios, issues that arose and related regimes.

The aim is to create a bridge between the clinical and technological side of data collection, storage and use. The recording interface can be used by anyone as it is a simple recording system, similar to the paper ones used within these two prominent development institutions; a prototype has been developed in this manner to make it easier and quicker for the proposed users to get the most out of it. Although in the future there will be a log of specific training, injury prevention and rehabilitation programmes, these will not be in use for the main reason that it is a new system and will only be used for the 10 athletes taking part in this study.

The athletes have been separated within this section giving a brief introduction to their specific backgrounds whilst keeping them anonymous. All athletes taking part are considered “Elite Athletes” by both participating institutions and other industry experts and are taking part with a view to improving their specific areas and to have a digital record of this for future use.

Athlete Selection Process

Due to the variance of athletes in the modern sporting world, the research aims to gather information across the board by coupling in various sporting areas. This ideal will give the research a better insight into an athlete's abilities whilst not hindering the results to a specific sport. In one instance, with regards to rugby union, there will be a total of two forwards and two backs as they are seen as very different athletes in terms of training and injury analysis. The breakdown is as follows.

3 x Senior Elite Hurlers
3 x Senior Elite Gaelic Footballers
4 x Senior Elite Rugby Union Players

Overall, the specific selection of athletes for this monitoring programme will give great insight into this area from different backgrounds.

Introduction to Measurement Techniques

Below is a table explaining the various functional measurement techniques that will be used during this study and a brief introduction to each one.

Category	Description
Weight (kg)	Athlete's body weight.
Triceps (cm)	Size of athlete's triceps (measured in centimetres).
Biceps (cm)	Size of athlete's bicep (measured in centimetres).
Chest (cm)	Size of athlete's chest (measured in centimetres).
Thigh (cm)	Size of athlete's thigh (measured in centimetres).
Calf (cm)	Size of athlete's thigh (measured in centimetres).
Combined Muscle Factor (cm)	Combined muscle size of athlete's 5 categories above (measured in centimetres)
Straight Leg Raise (R)	Raise right leg directly upwards whilst lying on back to a 90 degree angle.
Straight Leg Raise (L)	Raise left leg directly upwards whilst lying on back to a 90 degree angle.
Shoulder Mobility (R)	Move right shoulder in a 360 degree circular motion without stress or stoppage.
Shoulder Mobility (L)	Move left shoulder in a 360 degree circular motion without stress or stoppage.
Hip Flexor (R)	Stretch right leg as high as possible upwards whilst lying on stomach.
Hip Flexor (L)	Stretch right leg as high as possible upwards whilst lying on stomach.
Glute Bridge (R)	Hold right leg parallel off the ground while left supports body at 45 degree angle.
Glute Bridge (L)	Hold left leg parallel off the ground while left supports body at 45 degree angle.
Rotational Stability (R)	Standing position, turn body at hip right and hold.
Rotational Stability (L)	Standing position, turn body at hip left and hold.
Shoulder Lift Off	Lying flat on ground, hands on back of head, lift upper body off ground.
Trunk St. Press-Up	Simple press up position, holding half way on way down and back up.
Lunge & Twist (R)	Lunging forward on right leg and turning withhold to the opposite side.
Lunge & Twist (L)	Lunging forward on left leg and turning withhold to the opposite side.
Hurdle Step (R)	Stepping over height barrier (1/3 height of body) with right foot and holding.
Hurdle Step (L)	Stepping over height barrier (1/3 height of body) with right foot and holding.
Squat	Holding unweight bar on shoulder and squatting as low as possible with hold.

Table 3.0

The term "N/A" will be used if a specific athlete does not require measurement or cannot partake in a certain area. For example, a non-injured athlete will have N\A in the "Injury Rehabilitation Level" section.

Introduction to Wearable and Monitoring Devices

Below is a table explaining the various wearable devices and monitoring techniques that will be used during this study and a brief introduction to each one. This table also includes a short but concise advantages and disadvantages section.

Equipment Type	Applications in Applied Settings	Advantages	Disadvantages
Catapult GPS Cost: €80,000 (per annum)	Effective way to track group and individual training load and performance. Allows for individualised training prescription. Allows for predictive training load based on retrospective field drills database. Provides good competition amongst players based on training, conditioning and match performance. Indoor tracking system is available.	A true 10 Hz GPS unit Easy to use software and hardware. Provides live data stream for all velocity and distance measures allowing for session monitoring or modification to ensure appropriate training stimulus. "Sprint" and "Openfield" software allows users to write bespoke metrics for analysis. The leading GPS provider with continue improvements in software and hardware. Good battery life and the units are robust	Typical Error of ±6% (x/÷ 1.06) Acceleration and deceleration data is not validated and unreliable Large variation in the absolute number and magnitude of acceleration and deceleration events.
Firstbeat Heart rate and sleep analysis. Cost: €3,000 - €4,500 (once off)	Effective way to track the internal cost of imposed training load. When coupled with GPS you have a way to measure the internal cost versus the external output for training and match performance.	Easy to use software and hardware. Good receiver range and ability to monitor within large stadiums. Provides good live data stream for large groups of athletes allowing for session monitoring or modification to ensure appropriate training stimulus. Provides Heart Rate Variability analysis (built in to the software or allows users to export raw data to a monitoring database) and sleep analysis ("Bodyguard" unit worn during sleep and downloaded post event).	Typical Error of ±6 to 9% (x/÷ 1.06 to 1.09) The software does not allow for user flexibility and raw data is typically exported to monitoring databases. The belts are not robust, water damage, battery life, straps breaking are all issues

Linear Position Transducers (“Tendo Unit” and “Gym Aware”) Cost: €1,300 - €1,8000 (once off)	An effective means of tracking velocity and power in the gym setting without the need for force plates. Long term monitoring of neuromuscular performance and individual athlete progression. Allows for velocity based training programmes for large groups of athletes.	Easy to use and set up. Portable and robust units for the gym environment. Visual feedback is easy for players and coaches to understand. Provide good feedback to players and creates competition during gym and weight training sessions.	GymAware has some Bluetooth connectivity issue at times. Double differentiation calculations is an issue with the power output data on rotary encoders
OptoJump Cost: €2,000 - €3,000 (once off)	An effective means of tracking velocity and power in the gym setting without the need for force plates. Long term monitoring of neuromuscular performance and individual athlete progression.	Provides excellent feedback and long term tracking of players within the OptoJumpNext software Software allows bespoke tests to be administered (RSI from various heights, multiple jumps etc.) Portable, easy to use and set up. Reliable data	You need a laptop to use the software and equipment and this can be an issue in a busy gym.
Jump Mat or Switch Mat Cost: €150 - €1,200 (once off)	Provides an easy way to monitor neuromuscular performance or fatigue.	Portable, easy to use and set up. Easy output for the players to understand. Allows for multiple tests to be administered (CMJ, RSI, Contact Time)	Reliability of the data compared to a force plate, users must be aware of the Typical Error. Jump height calculation.
Brower Speed Gates Cost: €1,300 - €2,000 (once off)	Monitoring acceleration, agility and velocity for individual athletes and large groups. Provides the coaching group with important performance data and creates competition amongst the playing group.	The equipment is portable, easy to use and set up Output is clear and easy to understand for the players and coaches.	Validity and reliability of the data, users must be aware of the Typical Error. Cannot be used in light rain conditions
Urine Osmolality Cost: €1,400 - €2,000 (once off)	Monitoring hydration levels and the potential link to performance	The equipment is portable, easy to use and set up Output is clear and easy to understand for the players and coaches.	Validity and reliability of the data, users must be aware of the Typical Error.
Musculoskeletal monitors (Lafayette muscle testing, isokinetic measuring systems) Cost: €800 - €1,200 (once off)	Monitoring musculoskeletal status is a way to measure individual response to training, ensure the prescription of appropriate training loads and potentially diminishing injury risk.	Hand held Lafayette is portable and easy to use. Allows for multiple musculoskeletal tests to be administered to large athlete groups.	Validity and reliability of the data, users must be aware of the Typical Error.

Table 4.0.

Introduction to Individual Athletes

This study monitors athletes from three different disciplines: Gaelic football, hurling, and rugby. Three senior panel Gaelic footballers have participated in this athlete monitoring study. All three hurlers included in this research project are taken from various Senior Hurling Panels. Significantly, all hurlers and Gaelic football players are amateurs, and manage their training schedules around full-time employment. In addition, four rugby union athletes are included in this study.

Footballer 1:

Footballer 1 ("**F1**") is a full-forward on a Senior County Football panel. This athlete has been playing for the Senior Football team for the past three seasons and played for the minor team in previous years.

F1 has had major knee ligament issues in the past, mostly during his time at minor level. However, in the past 12 months this issue has begun to hinder his abilities with regards to speed and full pace motions. F1's knee ligament injuries have plagued his athletic career, and he is currently undergoing strength and conditioning practices to improve these issues. However, F1's injuries have not been digitally tracked. Therefore, this study will focus on monitoring F1's rotational stability and squat functionality.

Footballer 2:

The second Gaelic footballer is a goalkeeper who is also on a Senior County Football panel, as well as playing weekly for his local club. Footballer 2 ("**F2**") has been a pivotal member of the senior panel for the last 8 years.

F2 has no major longstanding injuries but is looking to improve his lower body strength, in order to gain a competitive advantage. The training regime has been tailored to F2's specific strength and conditioning needs, and will be continually monitored through this digital platform. In addition, the athlete's mobility in his lower body will be digitally measured to ensure that the change in training pattern does not negatively affect these functional abilities.

Footballer 3:

The third and final Gaelic footballer taking part in this study debuted as a member of the Dublin Senior football panel last year. Footballer 3 (“**F3**”) concurrently plays for his local club to gain more experience and cement his presence in the Dublin line up. F3 currently plays as a central midfielder, one of the most physically demanding positions in Gaelic football. F3’s additional training and game time has the potential to cause harm if not properly managed.

F3 has serious shoulder mobility issues that have affected his career from a young age. Significantly, F3 suffers from this issue in both shoulders; this makes a training regime slightly easier to implement as there will be no issue of “over-training” one section of his body. This shoulder issue, coupled with his current rehabilitation for an ankle injury gives this athlete a unique opportunity to have multiple areas of his body monitored, with the aim of improvement.

His ankle injury will be measured on a 1-5 rehabilitation scale, the same functional monitoring system used by the majority of participating athletes. He will begin at level 0 as he has not undergone any rehabilitation prior to this study.

Hurler 1:

Hurler 1 (“**H1**”) is a midfielder who plays extensively for both club and county continuously throughout the calendar year. Due to his various commitments, this player has, on average, a total of 5 elite training sessions and has up to 3 more gym sessions with one day off per week to recuperate.

Currently, H1 has no major injury concerns. He wishes to increase his endurance, with a view to increasing his flexibility to this end. To achieve this goal, this player’s reading from both wearable devices and functional observations will be crucial. Any improvements in his endurance will be tracked through the digital correlation. Three main flexibility areas will be recorded: (i) Shoulder Lift Off, (ii) Hip Flexor and (iii) Glute Bridge abilities.

Hurler 2:

Hurler 2 ("**H2**") is a central defender of a very high calibre. This athlete has been established in the senior league for nearly a decade, and previously played at all underage levels. H2 is also an active player at club level, doubling his sporting activity during the week.

Unfortunately, H2 ruptured a disk in his spine just over a year ago, leaving him unable to train for a long period of time. In attempt to heal his injury, H2 underwent massive amounts of rehabilitation and physiotherapy. Currently, he has completed his recuperation phase, but does not have the requisite fitness to play at the top level of hurling. In particular, H2's mobility and flexibility have become significant issues as a direct result of this major injury. H2 hopes to drastically improve his lower body functional mobility before the new season starts. His full rehabilitation programme has been recorded and will be used in conjunction through the digital platform to gain a better overall perspective and improve the affected areas.

Hurler 3:

Hurler 3 ("**H3**") is also an active club and senior county athlete. He is considered a "utility back" as he often switches between defensive positions to suit the team's needs.

As a utility player, this athlete is constantly changing positions and very often has competing physical requirements week-by-week. As a defensive player, this athlete requires a great deal of strength. However, H3's senior coaches have identified his lower body strength as a major issue. In particular, they note that his vertical jump is weak for an elite athlete. This study, therefore, will focus on digitally recording H3's lower-body muscular abilities alongside his current training regime.

Rugby Player 1:

Rugby Player 1 (“**RP1**”) plays in the All Ireland League (AIL), which is the top level in Ireland behind professional, provincial and international level. This year, RP1 graduated from the renowned Leinster Rugby Academy, and is currently training with the senior squad at the age of 22. He considers himself a fullback, but often plays as a winger to suit various squad rotations. Both of these positions require comparable attributes of overall strength and fitness.

RP1 experiences an accelerated transition from amateur to professional rugby. As such, he has been unable to put on the large volumes of muscle necessary to play professional rugby. At the moment, due to a lack of game-time with any senior Leinster team, this athlete wishes to work heavily on his strength abilities. By contrast to the difficulties in traditionally tracking such measurements, a digital athlete monitoring system provides a simple and measured solution.

Due to persistent hamstring strain, RP1 will also be undertaking rehabilitation protocols. With proper precautions, this injury should not drastically hinder RP1’s ability to train, but it will need to be monitored on a regular basis and recorded.

Rugby Player 2:

The second participating rugby union athlete is a prop forward. Rugby Player 2 ("**RP2**") currently plays at AIL level, having previously played for both the senior Leinster and Irish International teams on numerous occasions. RP2 has played at the top level of Irish rugby for over 14 years and has amassed a huge amount of personal and team accolades including, a winners medal in the European elite rugby championship, the Heineken Cup. Despite his lengthy career, there are relatively few professional records of RP2's functional abilities. Therefore, for this player, a full body functional and mobility study will be hugely beneficial.

RP2 has endured his fair share of injuries – mostly neck and back problems as a result of his position in the front row. RP2 has been given the opportunity to disclose any past injuries, to the best of his knowledge, using a digital user interface. The digital interface affords both RP2 and his team to digitally transcribe his past injuries in order to better treat him in his current state and in the future.

The weakness of RP2's upper body poses a problem in restoring full functional mobility. However, if a system of graduated milestones is implemented, it is hoped that the digital platform will produce results.

Rugby Player 3:

The third rugby union player that will be partaking in this study plays for the Ireland under-20's team as their starting out-half, one of the most skilful positions in Rugby Union. In addition, Rugby Player 3 ("**RP3**") plays at under-20's level for his province and senior AIL club on a weekly basis. By RP3's account, last year he averaged 6 days of training and or competition per week.

RP3 has a serious medical history, involving a heart condition (Hypertrophic Cardiomyopathy [HCM]). This condition is managed through heart rate and variability monitors, which RP3 wears during all training and match instances. If any abnormalities or issues are reported by those devices, RP3 is removed from strenuous activity.

Over the coming months, RP3 will be training at a completely new level. In acclimatising to professional rugby union, RP3 will need to extensively work on his strength, whilst ensuring his heart condition remains stable. In order to measure RP3's strength, data will be recorded through wearable monitors. Any training regimes prepared for this athlete must be cognisant of his heart condition.

Rugby Player 4:

The fourth athlete who will be measured plays rugby at an All-Ireland League (AIL) level, and was previously a member of the Leinster Rugby Academy and Irish International 7's team. Rugby Player 4 ("**RP4**") is also currently training towards a competing in his first marathon. The athlete currently play as a first centre, a physically demanding position that requires a high level of strength and fitness.

RP4 has an injury history which includes a rotator cuff injury in his right shoulder and a dislocated left hip. Both issues currently hinder RP4's training regimes and limit his mobility in both joints. The primary goal of this case study is to improve both RP4's shoulder and hip flexor mobility.

Recordings from Athlete Monitoring

All functional, mobility and injury related recordings are done on a 0-5 scale. '0' represents a non-existent compliance whilst '5' represents optimal functionality for the specific athletic requirements. The study also includes a reading for complete muscle gain. This reading is illustrated by either a positive or negative figure, which represents the average gain in muscle by centimetre measurement.

<u>Footballer 1:</u>

The first measurement (09/03/15) showed some significant changes in F1's ability. A new programme to increase rotational stability and squat ability was incorporated into his normal training regime. F1's stability had increased substantially, while his leg strength also showed signs of improvement. <u>Results: Rotational Stability (L) 3: Rotational Stability (R) 3: Squat 3.</u>

Before the second recording (31/03/15), F1's coaches could see that his stability was improving. Therefore, after the first milestone, they decided to concentrate on his stability more than his squat abilities. This specialised focus resulted in an improvement in the athlete's abilities, in particular motion and stability. <u>Results: Rotational Stability (L) 4: Rotational Stability (R) 5: Squat 3.</u>

The training platform was slightly altered before the final measurement (24/04/15) to include a degree of squat ability, whilst maintaining rotational stability as the primary objective. The changes in F1's abilities over such a short period of time were remarkable. Not only did F1's stability improve, but his coaches reported that his overall match performances were consistently of a high standard. F1 achieved perfect rotational stability throughout his lower body by the final assessment, a comprehensively satisfying result. <u>Results: Rotational Stability (L) 5: Rotational Stability (R) 5: Squat 4.</u>

Conclusion:

As the various trainers and the athlete subject agree, this trial period was a major success for F1. The training resulted in notable improvements, particularly on areas which have been troubling this athlete for a long time. Bringing F1's stability up to a perfect standard through this monitoring platform was a huge achievement – one which can be reused for similar athletes with the same problems. It is important to note that F1 focused intensively on his stability, a key factor in reaching this unforeseen goal. The digital monitoring techniques used simplified the tracking and altering of his training programme and ultimately led to the success of the candidate.

Footballer 2:

F2 demonstrated only minor changes after the first measurement (09/03/15). According to his coaches, this result can be explained by the difficulty in gaining pure muscle in an athlete's lower body, especially one who is undergoing extensive training outside of this particular study. Results: Hurdle Step (R) 3: Hurdle Step (L) 3: Lunge & Twist (R) 4: Lunge & Twist (L) 3.

During the second phase (31/03/15), F2 exhibited greater improvements even though his training regime remained constant. However, in the course of this training, F2 increased his weights, a probable reason for his increase in size and strength. Results: Hurdle Step (R) 4: Hurdle Step (L) 4: Lunge & Twist (R) 4: Lunge & Twist (L) 4.

The final recording (24/04/15) showed expanded abilities in motion and strength, with one aspect (Hurdle Step (R)) finishing at the top of the spectrum. These improvements are largely due to the absence of injury and a drop in game-time. Both factors largely contributed to the effectiveness of the study. Results: Hurdle Step (R) 5: Hurdle Step (L) 4: Lunge & Twist (R) 4: Lunge & Twist (L) 4.

Conclusion:

F2 plans to continue this training regime as he and his coaching team believe it to be beneficial/ F2’s choice demonstrates the effectiveness of a transparent and measured timing programme. Again, due to the success of this training regime, it can now be added to an athlete database and used again with other similar athletes aiming to achieve the same or similar goals.

Footballer 3:

F3 is currently on an athletic hiatus as he is undergoing treatment for a recent ankle injury. This rest period afforded the perfect opportunity for F3 to work on his shoulder issues through this digital monitoring platform as he could fully concentrate on the programme. During the first recording (09/03/15), it was obvious that there was little improvement in this athlete's shoulder mobility, although his ankle injury was slowly healing. Results: Shoulder Mobility (R) 2: Shoulder Mobility (L) 2: Injury Rehabilitation Level 1.

The second recording (02/04/15) showed a great deal of improvement in F3's ankle injury, with some slight improvement in his shoulder mobility on both sides. Despite predictions that F3's ankle injury would not meet IRL standards (Injury Rehabilitation Level 5) by the end of this study, this second milestone proved F3 was close to meeting the requisite fitness level. The digital recording demonstrated that his programme was not only working for injury rehabilitation but also on improving his desired training areas. Results: Shoulder Mobility (R) 3: Shoulder Mobility (L) 2: Injury Rehabilitation Level 4.

Unfortunately, this athlete suffered a recurrence of his ankle injury between recording 2 and 3 (24/04/15), resulting in a lengthening of his expected injury lay off-time. The coaches decided to stick with the current regime as it was working, but are using the recorded data to alter it once he returns to IRL 4 to better suits his needs. The tracking of this player's rehabilitation programme allowed the athlete stakeholders to identify when it became too strenuous on F3. In relation to F3's shoulder mobility, there was a slight, but not hugely significant, improvement recorded. Results: Shoulder Mobility (R) 3: Shoulder Mobility (L) 3: Injury Rehabilitation Level 2.

Conclusion:

The recovery regime set out was perfectly measured for the beginning of the programme, but unfortunately was not altered as the athlete went forward and hence hindered his return to full fitness. As previously stated, the athletic therapists have been able to pinpoint when the athlete's rehabilitation programme should have been changed through the digital monitoring platform. Therefore, F3's coaches are alert to the potential need to alter his training regime in the future. As for his shoulder mobility, there was overall a substantial improvement in both sides, but not as much as was hoped. F3's training regime has now also been altered going forward to include new exercises that may better suit his needs.

Hurler 1:

A clear increase was noted in all aspects of this player's flexibility, showing a small recordable improvement in the predefined regions after the first milestone (07/03/15). H1 has continued his demanding training schedule during this study and has felt no ill-effects due to the additional functionality training. Results: Hip Flexor (R) 3: Hip Flexor (L) 3: Glute Bridge (R) 4: Glute Bridge (L) 2: Shoulder Lift Off 3.

Due to success of the first recording, H1 was kept on the same routine, with only a few changes aimed towards incremental progression. There again were some slight improvements in this athlete's flexibility and no major injury concerns noted during the second period (30/03/15). Results: Hip Flexor (R) 3: Hip Flexor (L) 3: Glute Bridge (R) 4: Glute Bridge (L) 3: Shoulder Lift Off 4.

The third phase of recordings (25/04/15) demonstrated an increase in H1's flexibility. Most notably, H1 achieved achieving the highest grade in the Shoulder Lift Off category in the whole study. Significantly, the other lower body areas showed only a moderate enhancement as this is a difficult area to complete a vast general improvement quickly. Results: Hip Flexor (R) 4: Hip Flexor (L) 3: Glute Bridge (R) 4: Glute Bridge (L) 4: Shoulder Lift Off 5.

Conclusion:

Due to the diverse characteristics of this athlete's training regime, the results may not look as comprehensive as others. However, on further inspection, H1's results illustrate notable achievements. Looking forward, H1's performance coaches are changing his training regime slightly to achieve better results in specific areas, whilst aiming to build muscle in his upper body now he has much better flexibility in that region.

Hurler 2:

H2 suffers from a serious back issue, which, without rehabilitation techniques, would put an end to his hurling career. At the beginning of the study, H2 aimed to slowly increase his lower body stability and mobility alongside his training to return to top level hurling. With his long-standing injury in mind, the first recording (07/03/15) showed a good improvement. Results: Straight Leg Raise (R) 2. Straight Leg Raise (L) 3. Rotational Stability (R) 1. Rotational Stability (L) 1.

The second recording (30/03/15) exhibited far-improved stability in H2's lower body. H2 demonstrated a much greater ability to rotate his hips in each direction than before. While his leg-raising functionality did not show much improvement, the second recording showed a levelling in the capabilities of both legs. Results: Straight Leg Raise (R) 3. Straight Leg Raise (L) 3. Rotational Stability (R) 3. Rotational Stability (L) 2.

Unfortunately, this athlete suffered a recurrence of his back injury prior to completing this final recording. The chronic injury was re-triggered in a non-athletic related instance and H2 is currently undergoing the beginning phases of rehabilitation. Results: Not Available.

Conclusion:

For the first two phases, this athlete appeared to be improving gradually. The recurrence of H2's back injury was hugely unfortunate. Positively, based on the recorded data, H2 has a proven rehabilitation programme at his disposal once he has recuperated.

Hurler 3:

Gaining muscle in a large area of the body is very hard to do, but relatively easy to record through simple measuring tools (e.g. body fat analysis, measuring muscle size, etc.). H3 was put on a similar training programme to one of the rugby players in this study, with more emphasis on lean muscle gain than muscle weight. At the time of the first recording (07/03/15), there was some improvement in this area and H3's trunk press up ability. Results: Combined Muscle Factor +2.2 (overall). Trunk St. Press Up 3.

Due to H3's demanding game schedule, his strength training continued, but not as a matter of priority. H3 competed at both club and county level simultaneously, whilst attending normal day to day hurling training. However, at the second stage of recording (30/03/2015) H3's muscle gain still exhibited a slight improvement. Results: Combined Muscle Factor +3.1 (overall). Trunk St. Press Up 3.

H3 had a large push from his coaches for improvement between the second and third recording (25/04/15) instances. H3 gained a substantial amount of recorded lean muscle during this period and his trunk press up ability was also elevated to the next level. Results: Combined Muscle Factor +6.9 (overall). Trunk St. Press Up 4.

Conclusion:

Although there was a lull during this athlete's trial period, his monitored results showed a quantifiable improvement. Importantly, this training programme, when properly followed and recorded, was suited to H3's personal needs. While H3's extensive training is not ideal for working on functionality, the success of the programme in spite of these circumstances must be highlighted. The digital recording system can be used for athletes in a position similar to that of H3.

Rugby Player 1:

The first milestone (12/03/15) did result in significant change in muscle mass for RP1. Some minor increases in RP1's lower body muscle size were recorded as he slowly increased various weight categories over time. However, his hamstring mobility has massively increased since commencing this programme. Results: Combined Muscle Factor +3.4 (overall). Straight Leg Raise (R): 3. Straight Leg Raise (L): 3

Due to RP1's enhanced hamstring capabilities, he was able to intensify his training before phase two (04/04/15). At phase two, the high-intensity training resulted in substantial growth in RP1's lower and upper body muscles. There was a slight increase in RP1's leg mobility, but his functionality score did not change. Results: Combined Muscle Factor +8.9 (overall). Straight Leg Raise (R): 3. Straight Leg Raise (L): 3

During the final period (01/05/15), RP1 "worked harder than ever before" according to his strength and conditioning coach. RP1's straight leg raise and overall muscle factor greatly increased and achieved high ratings on the functionality scale. Results: Combined Muscle Factor +11.4 (overall). Straight Leg Raise (R): 4. Straight Leg Raise (L): 4

Conclusion:

Overall, this was a very successful training period for this up-and-coming rugby star. Not only did RP1 achieve his original goals, he surpassed them. The tailored training programme allowed RP1 to strengthen an injured area nearly to the point of full rehabilitation whilst also putting on a total of 1.6 kilos of pure muscle. In addition, because all aspects of his training and rehabilitation programme were successfully collected and accurately stored, this success story will enable future athletes with similar injuries to have a transparent track record for their own treatment.

Rugby Player 2:

The first recording (12/03/15) showed some improvement in this athlete's abilities, mostly in his mobility. As his back and neck issues have been getting progressively worse over the last number of years, the fact that RP2 himself felt an improvement was a great measure of success. Results: Shoulder Lift Off: 2.

Unfortunately, between the first and second recording (04/04/15), the athlete incurred an injury during a match that resulted in him being unable to train for about 2 weeks. This break in training affected his progress and resulted in very little improvement from the last milestone. However, his injury is now being tracked through this monitoring system for the remainder of the study. Results: Shoulder Lift Off: 2. Injury Rehabilitation Level: 1

The final results (01/05/15) showed another respectable improvement in RP2's specific abilities, even while he is recovering from an injury. RP2's injury has been monitored and has improved dramatically on a physical and digital tracking plan. Results: Shoulder Lift Off: 3. Injury Rehabilitation Level: 4

Conclusion:

Even though this athlete incurred a substantial injury during the study, he was still able to maintain the training regime once it was slightly altered. In addition, once the injury was identified, it could also be recorded and worked through. RP2's injury was monitored through a Rotational Stability method that determined whether or not his quad injury was improving. RP2 hopes to return to a full 5 factor in the coming weeks in order to return to full training.

Rugby Player 3:

During the first training period (12/03/15), RP3 altered his training regime twice due to progressive issues with his heart. The third programme implemented appeared to suit RP3's particular needs, and RP3 exhibited a significant increase in his overall muscle strength. Results: Combined Muscle Factor: +3.5 (overall).

After the second recordings (04/04/15) were undertaken, it was clear that this training regime worked extremely well for RP3. Visual signs of increased muscle strength were apparent. In addition, no major heart issues were recorded by his wearable monitor during this time period. Results: Combined Muscle Factor: +7.1 (overall).

The final recording (01/05/15) for RP3 was delayed due to RP3's international duties. However, the international training resulted in an overall increase in strength and fitness. RP3's final readings showed dramatic strength increases and all monitor readings were normal, even during a tough playing period. Results: Combined Muscle Factor: +13.8 (overall).

Conclusion:

RP3 was ideal for this study as he could fully avail of the use of wearable technologies such as his heart sensor. These technologies, coupled with RP3's desire to improve on his strength and muscle led to interesting results. Once a suitable training programme was established, after two failed attempts, RP3 fully accomplished his goals. RP3 is continuing on this current platform and trainings schedule, and all his data will continue to be collected.

Rugby Player 4:

During the first intermittent measurement (08/03/15), there was no improvement in either the athlete's shoulder or hip with regards to mobility. The lack of positive results can largely be explained by RP4 acclimating to this new training regime. Results: Hip Flexor (L) 2. Shoulder Mobility (R): 2.

The second recording (04/04/15) showed a slight improvement in the athlete's hip mobility. An even better result for RP4's shoulder was garnered through the digital monitoring system. Using the protocol 1-5 system proved quantifiably that RP4 had achieved the targets for both areas. Results: Hip Flexor (L) 3. Shoulder Mobility (R): 4.

The final examination (08/02/15) carried out on RP4 focused on determining the major changes to his body and how the digital system impacted him. While RP4's shoulder mobility did not change substantially from the second recording, the athlete's hip had improved between phases. Results: Hip Flexor (L) 4. Shoulder Mobility (R): 4.

Conclusion:

In total, the results for this athlete are remarkable. RP4 has doubled his shoulder and hip mobility whilst improving various other functionalities along the way. RP4's previous training programme was not properly tailored to him, and, importantly, did not keep his results for comparison. RP4's recorded data will now stand to aid him personally, as well as other athletes hoping to improve in the same areas.

Athlete Monitoring Interface

Below is a screenshot of the user interface for the monitoring system that was designed for this dissertation. It contains the information regarding the final participant, Rugby Player 4.

Player:	**Rugby Player 4**
Date:	**2nd May 2015**
Team:	**Lansdowne RFC**

Body Composition	**Previous**	**Current**	**Average**
Combind Muscle Factor	162.4	162.6	162.50
Weight	83.8	83.9	83.85

Mobility	**Previous**	**Current**		**Average**
Straight Leg Raise (R)	4	4	0	4.00
Straight Leg Raise (L)	4	4		4.00
Shoulder Mobility (R)	4	4	1	4.00
Shoulder Mobility (L)	4	5		4.50
Hip Flexor (R)	4	5	1	4.50
Hip Flexor (L)	3	4		3.50

Stability	**Previous**	**Current**		**Average**
Glute Bridge (R)	5	5	1	5.00
Glute Bridge (L)	4	4		4.00
Rotational Stability (R)	5	5	0	5.00
Rotational Stability (L)	5	5		5.00
Shoulder Lift Off	5	5		5.00
Trunk St. Press-Up	4	5		4.50

Function	**Previous**	**Current**		**Average**
Lunge & Twist (R)	5	5	0	5.00
Lunge & Twist (L)	5	5		5.00
Hurdle Step (R)	4	5	0	4.50
Hurdle Step (L)	5	5		5.00
Squat	5	5		5.00

Figure 1.0

From the image above you can see, in an easily viewable format, Rugby Player 4's results. The figures shown in the "Previous" column, portray the second last monitoring results, whilst the "Current" column show the final ones. There is also an "Average" section giving the user the average ability over the last two recording instances.

Within the "Current" column, there is also some colour coded results. These show how the athlete ranks overall, and in comparison to related exercises. For example, RP4's "Glute Bridge is at 5 for his right leg, and 4 for his left. This leaves a figure of 1 beside the results as it is the difference between the athletes two Glute abilities. The colour coding also gives the user a definitive answer as to how the athlete's abilities are currently and how they have been improving over a predefined period of time. The colour coding of figures are as follows:

1 – 2	Red (poor)
3 – 4	Amber (moderate)
5	Green (good)

Table 5.0

Athlete Monitoring Conclusion

This athlete monitoring study has resulted in improved athlete abilities and effective injury prevention. The success of this programme was quantitatively evidenced during the second recordings, when the athletes' results became clearly defined. The training programme established by this study has allowed the functionality of elite athletes to be monitored and effectively stored. This data can be compared to previous results in both specific categories and in broad terms to benefit individual athletes, and those with similar demands. In the past, physical data was collected intermittently and not efficiently retained. By contrast, the elite athlete monitoring system offers a quantified and transparent approach to elite training.

In addition, the individual athletes have responded positively to the training programme. All but one athlete (who is leaving the sport) have chosen to continue with this style of training platform as they believe it has benefitted them greatly. Even those athletes who sustained injuries during the study period have achieved positive results. These injured athletes will continue to monitor their rehabilitation through the digital platform, in accordance with advice from their respective medical teams. In particular, RP4's functionality and athletic ability has progressed immensely over the course of the study, and despite recently reigniting a lower back problem, he will continue with the training programme.

Further, it is important to note the demonstrable ease with which the majority of the staff involved were able to engage with the system. Despite teething problems during the first use, towards the end of the study, it became evident that all clinical users of the system found it easy to use. Specifically, users reported that functions such as printing results, forwarding regimes and results and creating and recording new exercises were completed with ease.

Overall, it is clear that this primary research study showed that an athlete's physical well-being and abilities can be accurately tracked using a digital monitoring system. The results have proven, together with the readings themselves, that an athlete monitoring system can support the decisions made by performance, rehabilitation and clinical teams. Not only can this system aid these teams individually, but it can bring these areas together into one accessible and readable structure available to all athlete stakeholders.

Primary Research Conclusion

After extensive research was carried out with this group of elite athletes and industry experts, the study has resulted in direct positive feedback and significant quantitative results. The initial idea of running tests on athletes and interviewing industry experts quickly evolved into a comprehensive athlete monitoring system.

The athletes responded exceptionally to the monitoring tasks and exhibited marked improvements throughout the study. As aforementioned, all but one of the participating athletes will be continuing with this method of digital recording. This feedback is significant as ensuring user and benefactor acceptance is hugely important in the success of a new system. I will refer to the final recordings diagrams for the full evaluation of each athlete (**Appendix C)**.

As for the expert opinions, the feedback received clearly demonstrated a demand for these types of systems to be globally used, as long as they are correctly established and directed. The table (Table 3.0) shows the advantages and disadvantages – according to industry experts – of each of the major digital monitoring tools available for elite athletes and their performance teams. Where available, scholarly articles have been cited to confirm the accuracy of this analysis. (Mary Rodgers, 2012. Chris Bauer, 2015. Paolo Bonato, 2005) However, some of the systems are too modern and recent to the market for full analysis. Therefore, in relation to these systems, the first-hand knowledge of users and expert sporting personnel is extremely valuable to this study.

The overall inclusion of the primary research in this study was of the utmost importance. Monitoring data is not widely available due to the advanced technology behind athlete systems. Therefore, the input of industry experts as well as real life athlete data is essential to the effectiveness of athlete monitoring systems. If the mentality of utilising the technology to enhance athlete capabilities is going to succeed, it must become an industry standard. It is of vital importance that this technology is open and affordable, so that players at all levels may benefit from digital tracking.

CHAPTER 4 – Closing Remarks

Future Work

As there is endless potential in the sporting industry for monitoring systems, there is a vast amount of research that needs to be completed into the future. Below is a brief list of the potential different areas for research:

1. A large scale monitoring research project:

The primary research conducted with the group of athletes in this study showed great potential for further research. Ideally, a large developer of monitoring tools, such as Kitman Labs, would work with a globally-recognised elite sporting body in a large-scale monitoring project. If such a project was carried out amongst a larger group of athletes over a longer time-period, the results would be highly influential. Although the athlete monitoring recordings within this study show proven results, the success of the system cannot be generalised until it is tested on a greater athlete population.

<u>2. Universal design and testing of an “Electronic Athlete Health Record (EAHR)”:</u>

While a multitude of exceptional monitoring systems currently exist, elite athlete training could be tremendously advanced through a universally-used electronic athlete health record. Creating and moulding a system with the following characteristics could lead to the industry flourishing;

- easily integrated into any environment;
- contains a defined set of standards for data entry, storage, transfer and analysis to ensure the information recorded can be properly used;
- exhibits a “user friendly” interface and design for industry experts and non-technical users; and
- adaptable to any sporting environment in any language.

It is near impossible to create the ideal system, but completing a baseline of these characteristics could potentially lead to a worldwide athlete monitoring system that can be used by anyone. As discussed previously, starting these recordings from a young age has its advantages and disadvantages. The main disadvantage, however, being a hindrance on an athletes future professional contract negotiations. But is the potential wage of an athlete more important than their health?

Recommendations

In relation to the potential for future work below are some recommendations based on the results of this dissertation:

1. Try to ensure that the group of athletes being monitored have very different physical attributes and goals, as this will produce more expansive results.

2. Although there was a unique system developed for this specific study, utilising a fully tested and more technologically advanced system will help with time management. Manual entry of data is time-consuming and can lead to errors. However, these systems may cost a lot of money to install and license. To finance these systems, perhaps approach a systems manufacturing company for funding.

3. As was discussed previously, any further study should include a large pool of data subjects. In addition, injured athletes should be included in order to test the impact of data recording directly on rehabilitating injuries.

4. The development of an Electronic Athlete Health Record requires a vast amount of work. A trial system could be developed, or even duplicated from ingredients of current systems. For example, HealthOne (Web Administrator, 2015), is one the most widely used Electronic Health Record systems in Ireland in the primary care sector. This software could be tailored to meet the needs of elite athletes; the interface could be maintained whilst its internal specifications could be changed for athlete tracking purposes.

5. The last recommendation is to start using these systems for younger elite athletes. Ideally, such systems should be implemented once young athletes reach a level of high competitiveness (minor level for GAA players, Under 18’s for Rugby etc.). Academic opinion asserts that monitoring the physical attributes of elite athletes at this stage could prove advantageous. (Dr. Neeru Jayanthi, 2010) The tracking system should be similar to that implemented in this study and, as recommended, should be user-friendly and affordable. In order to facilitate pricing, systems for younger elite athletes can be scaled back and minimalized to core functions.

Final Conclusion

In sum, has this dissertation proven that using digital recordings and wearable technology can help improve an individual athlete's abilities during training and injury rehabilitation? From the results of the primary research, there is clear proof that digital recording produces the predicted results. Not only can electronically recorded data be tracked and categorized, but it can be analysed by the athlete's performance and medical team to underscore any decisions in relation to that athlete's training regime.

In addition, the recorded data can be re-used. Outside of the players profiled in this dissertation, other athletes have expressed a desire to undertake this monitoring technique. One such athlete, who suffered similar shoulder issues to a participant, incorporated the participant's exercises and monitoring techniques into his own training regime. This example demonstrates the pragmatic nature of athlete tracking systems, and the ability of athletes to take control of their training and rehabilitation regimes.

The industry experts gave a frank and comprehensive insight into current trends in athlete monitoring systems and their potential development. Some of the experts interviewed work for one of the largest monitoring systems developers in the world, and are the key contacts in the industry. Their opinions were invaluable in confirming that tracking systems not only can work, but can thrive under the right environments.

There is little room for error in elite monitoring programmes. As previously stated, input controls must be made standard and protocols must be followed for basic functions such as saving, copying and transferring data within the system. These protocols are one of the few non-clinically vital components in achieving a highly functioning athlete monitoring system.

The final readings in the case studies clearly illustrate that the goals set out at the beginning of this project were achieved. As there is very little direct collegiate literature based on digital monitoring techniques for elite athletes, the literature review was expanded to include all relevant information. Therefore, this dissertation has analysed similar tools and techniques in the area of clinical and technological research.

Elite athlete monitoring is a budding research that will require extensive further research. It is hoped that any future researchers will be able to use and reference this dissertation as a stepping stone in their pursuit. There are endless research opportunities in this field.

The key determination of this dissertation is that technology can be utilised to create profiles for athletes that can follow them throughout their career, wherever they may go, like an Electronic Health Record.

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Appendix:

A. Industry Expert Questions:

1. Have you ever been involved in the development or use of an athlete monitoring system? Specifically used for the overall monitoring of an athlete. If yes, please provide a brief detail of the system.

2. Do you believe that monitoring an athlete's physical attributes could improve their abilities and performance? Please give a short reason for your answer.

3. Have you ever thought that an injury might happen but the athlete involved insisted on continuing, then the injury did occur? If yes, please give a short description of the occurrence.

4. Could long term physical analysis of an athlete pose any issues in the present or future? Please give a short reason for your answer.

5. What is your opinion on an “Electronic Athlete Health Record” being available to all potential athlete stakeholders? This would contain relevant training, injury and rehabilitation regimes a specific athlete has undergone throughout their career.

6. Have you ever been involved in the use of electronic monitoring devices for athletes? Such as heart rate monitors, speed gates, respiration measurements etc. Please describe briefly if you have including your opinion of their use, advantages and disadvantages.

7. Do you believe that electronic monitoring devices (such as heart rate analysis) should be used by all elite sporting bodies? This primarily being for player safety and data collection. Please give a short reason for your answer.

8. What is your overall opinion of a digital monitoring system being used to better track an elite athlete’s training regimes, injuries and injury rehabilitation programmes? Please list any advantages and disadvantages you feel are relevant.

B. Ethical Approval

INFORMED CONSENT FORM FOR ATHLETES

LEAD RESEARCHERS: Luke Middleton

BACKGROUND OF RESEARCH:

This dissertation topic will aim to review and analyse the data that is recorded through wearable athlete devices. These recordings would be done in person as the athlete is training and recorded via a digital platform for use.

The overall goal is to combine various methods of athlete profiling tools with a view to better integration of the data for reasons such as injury prevention and training regime creation. This method has not been fully and comprehensively analysed in an accurate and readable format, which is what this research paper hopes to prove is achievable.

PROCEDURES OF THIS STUDY:

During the investigation, I will be analysing current existing data and data taken from elite athletes in a variety of sporting areas. Much of this analysis will be carried out within an elite athlete development organisation through their devices and computer systems. There will also be athlete examinations undertaken to achieve better quality data with regards to their functional movements and abilities. This information will be portrayed in tandem with the monitoring data for an overall evaluation of the athletes' abilities.

I hope to prove that the data taken from athletes throughout their exercise programmes contains information that can be better used for purposes such as training regimes creation, long term behavioural tracking and injury prevention

There will be three functional assessments in total of the various athletes taking part at three different times, the first starting in March 2015.

This study is fully compliant with the Data Protection Act 1988 and Data Protection (Amendment) Act 2003.

Individual results may be aggregated anonymously and research reported on aggregate results.

Consent Form for Athletes

DECLARATION:

- I am 18 years or older and am competent to provide consent.
- I have read, or had read to me, a document providing information about this research and this consent form. I have had the opportunity to ask questions and all my questions have been answered to my satisfaction and understand the description of the research that is being provided to me.
- I agree that my data is used for scientific purposes and I have no objection that my data is published in scientific publications in a way that does not reveal my identity.
- I understand that if I make illicit activities known, these will be reported to appropriate authorities.
- I understand that I may stop electronic recordings at any time, and that I may at any time, even subsequent to my participation have such recordings destroyed (except in situations such as above).
- I understand that, subject to the constraints above, no recordings will be replayed in any public forum or made available to any audience other than the current researchers/research team.
- I freely and voluntarily agree to be part of this research study, though without prejudice to my legal and ethical rights.
- I understand that I may refuse to answer any question and that I may withdraw at any time without penalty.
- I understand that my participation is fully anonymous and that no personal details about me will be recorded.
- I have received a copy of this agreement.
- I understand that physical recordings will be made of me; however, these will remain completely anonymous and can be withdrawn at any time.
- There will be no digital (video) recordings of these monitoring instances during the research period.
- Results can be reviewed by an individual athlete at any time during the study.

PARTICIPANTS NAME

SIGNATURE:

Date:

Statement of investigator's responsibility: I have explained the nature and purpose of this research study, the procedures to be undertaken and any risks that may be involved. I have offered to answer any questions and fully answered such questions. I believe that the participant understands my explanation and has freely given informed consent.

RESEARCHERS CONTACT DETAILS:

INVESTIGATOR'S SIGNATURE:

Date:

INFORMED CONSENT FORM FOR INTERVIEWEES

LEAD RESEARCHERS: Luke Middleton

BACKGROUND OF RESEARCH:

This dissertation topic will aim to review and analyse the data that is recorded through wearable athlete devices. These recordings would be done in person as the athlete is training and recorded via a digital platform for use.

The overall goal is to combine various methods of athlete profiling tools with a view to better integration of the data for reasons such as injury prevention and training regime creation. This method has not been fully and comprehensively analysed in an accurate and readable format, which is what this research paper hopes to prove is achievable.

PROCEDURES OF THIS STUDY:

During the investigation, I will be analysing current existing data and data taken from elite athletes in a variety of sporting areas. Much of this analysis will be carried out within an elite athlete development organisation through their devices and computer systems. There will also be athlete examinations undertaken to achieve better quality data with regards to their functional movements and abilities. This information will be portrayed in tandem with the monitoring data for an overall evaluation of the athletes' abilities.

I hope to prove that the data taken from athletes throughout their exercise programmes contains information that can be better used for purposes such as training regimes creation, long term behavioral tracking and injury prevention

There will be three functional assessments in total of the various athletes taking part at three different times, the first starting in March 2015.

For those being interviewed, you will be asked questions regarding the potential for a system such as the one being proposed and how useful it will be. This interview will take about 15 minutes per person and will be conducted on the interviewee's most convenient time. There will be no personal questions but opinions regarding the system and what it should include will be asked.

This study is fully compliant with the Data Protection Act 1988 and Data Protection (Amendment) Act 2003.

Individual results may be aggregated anonymously and research reported on aggregate results.

Consent Form for Interviewees

DECLARATION:

- I am 18 years or older and am competent to provide consent.
- I have read, or had read to me, a document providing information about this research and this consent form. I have had the opportunity to ask questions and all my questions have been answered to my satisfaction and understand the description of the research that is being provided to me.
- I agree that my data is used for scientific purposes and I have no objection that my data is published in scientific publications in a way that does not reveal my identity.
- I understand that if I make illicit activities known, these will be reported to appropriate authorities.
- I freely and voluntarily agree to be part of this research study, though without prejudice to my legal and ethical rights.
- I understand that I may refuse to answer any question and that I may withdraw at any time without penalty.
- I understand that my participation is fully anonymous and that no personal details about me will be stored.
- I have received a copy of this agreement.
- Any answers given can be changed or withdrawn at any time once completed.
- There will be no digital (video) recordings of these interviews, all will be done on paper and submitted to the researcher.

PARTICIPANTS NAME

SIGNATURE

Date:

Statement of investigator's responsibility: I have explained the nature and purpose of this research study, the procedures to be undertaken and any risks that may be involved. I have offered to answer any questions and fully answered such questions. I believe that the participant understands my explanation and has freely given informed consent.

RESEARCHERS CONTACT DETAILS:

INVESTIGATOR'S SIGNATURE:

Date:

END OF CONSENT FORMS

INFORMATION SHEET FOR ATHLETES

I am currently developing a dissertation topic to analyze data that is recorded through wearable devices, such as the ones used within top level athlete development organizations on their various athletes. These recordings would be done in person as the athlete is training and recorded via a digital platform for use. Each participant's data will be recorded and stored separately.

The overall goal is to combine various methods of athlete profiling tools with a view to better integration of the data for reasons such as injury prevention. Functional exercises will also be performed at three different instances throughout the study.

At any time during this assessment any athlete who wishes to remove him or herself from the study can do so and all recorded data will be deleted immediately. For each athlete there will be a total of three functional recording with which you will be taking part. These should take about 30 minutes each, similar to the current training regimes. The potential benefits for each athlete will be better recording of overall fitness and wellbeing with the potential to improve upon particular weaknesses in training and rehabilitation programmes.

All participants will be debriefed in person once the study has concluded. Participants may withdraw from taking part in the study at any time without penalty.

The participants will not view any digital material, such as profiling tools, prior to taking part in the study. The study will be 100% anonymous for each participant.

All recordings will remain private and none will be played in any public forum or made available to any other researcher or research team. If for any reason a participant believes they will be involved in a conflict of interest due to their participation, you are advised not to partake in this study.

INFORMATION SHEET FOR INTERVIEWEES

I am currently developing a dissertation topic to analyze data that is recorded through wearable devices, such as the ones used within top level athlete development organizations on their various athletes. These recordings would be done in person as the athlete is training and recorded via a digital platform for use. Each participant's data will be recorded and stored separately.

I hope, by undertaking this interview, to gain insight into an industry expert's opinion of athlete monitoring systems and their use. The questions asked are aimed to give opinions, critical analysis and potential pitfalls of an athlete centered monitoring system for use in training and injury prevention regimes. There will be no confidential questions asked and all answers will remain anonymous. The questions being asked will be the same for each industry expert. As seen above, there will be information required from each answer and not just a simple yes/no.

The interviewee will be able to stop the interview and have all records deleted at any stage, be it during or after the interview has been conducted. The interview itself will take about 15 minutes and will ask no personal questions will be asked, just questions regarding the proposed idea and how it would be best used. All interviewees will be fully debriefed directly after the interview and once the project has been completed. All answers given will be recorded on paper and the interviewee is under no obligation to answer any questions which they do not wish to. There will be no digital (video) recordings of the interviews.

All participants will be debriefed in person once the study has concluded. Should any participant wishes for their answers to be changed or deleted this will be done immediately, without consideration.

The participants will not view any digital material, such as profiling tools, prior to taking part in the study. The study will be 100% anonymous for each participant.

All recordings will remain private and none will be played in any public forum or made available to any other researcher or research team. If for any reason a participant believes they will be involved in a conflict of interest due to their participation, you are advised not to partake in this study.

Please note that each question contained in the interview is entirely optional and you can feel free to omit any question, which you do not wish to answer. With this, the researcher would be grateful if all questions are given an appropriate response.

Research Project Proposal

Definitions:

1. *Wearable Device: These are clothing and accessories incorporating computer and advanced electronic technologies. For this study they would be used to record heart rate, respiration and the speed of an athlete over 10, 20 and 50 metres. These recordings will not be viewed by anyone other than me.*

2. *Primary in Person Analysis: These will involve me recording athlete data as they are training. I will be logging the relevant data through a mobile device to be used for my primary analysis.*

3. *Functional Recordings: This is a recording of an athlete during training or physical exercise. The recording relates to the athlete's ability with regards to a specific exercise and will be recorded by myself.*

This dissertation topic will aim to review and analyze the data that is recorded through wearable athlete devices. These recordings would be done in person as the athlete is training and recorded via a digital platform for use.

The overall goal is to combine various methods of athlete profiling tools with a view to better integration of the data for reasons such as injury prevention and training regime creation. This method has not been fully and comprehensively analyzed in an accurate and readable format, which is what this research paper hopes to prove is achievable.

During the investigation, I will be analyzing current existing data and data taken from elite athletes in a variety of sporting areas. Much of this analysis will be carried out within the athlete development organization through their devices and computer systems. There will also be athlete examinations undertaken to achieve better quality data with regards to their functional movements and abilities. This information will be portrayed in tandem with the monitoring data for an overall evaluation of the athletes' abilities.

I hope to prove that the data taken from athletes throughout their exercise programmes contains information that can be better used for purposes such as training regimes creation, long term behavioral tracking and injury prevention.

The interviewees will be from a leading athlete development organisation, one of the largest producers of performance recovery tools in Europe and two elite athletic therapists from different professional sporting bodies. There will also be some athletic therapists involved in the interview process, these will also be from the above two companies. These interviews will be recorded on paper with each interviewee under no obligation to answer every question. There will be no digital (video) recording of these interviews.

Monitoring athletes through a digital format is a relatively new phenomenon, but one which has taken off and will continue to grow. The main area, which I am planning to research in this dissertation, is the constant monitoring of not only injuries and rehabilitation but also the inclusion of the exact training and exercise regimes each athlete is undergoing and how it affects them. This will be done using incremental functional analysis and comparison tools to define if a particular training regime is improving or hindering an athlete's abilities. These figures are easily recordable and once entered, can be stored for an infinite period of time and used by a wide variety of athlete stakeholders.

There is conclusive proof within the articles I have reviewed for my literature review that monitoring athletes training and injury processes can provide a valuable competitive advantage. With this, however, there is still drastic room for improvement and upscaling. Currently no major sporting body encompasses the idea of tracking both training and injury practices for the purpose of regime analysis. This tool could prove to be of huge benefit for both the athlete and their stakeholders.

New technology in this area is being constantly discovered. For example, a new system to measure the impact and effectiveness of an athlete is currently in the patent pending stage. This could revolutionize in game analysis of an individual athlete.

All persons whom take part in this study will be given a personal one on one debriefing of the entire project once completed, with a highlight on the specific are with which they were part of. There will be a debriefing for the athletes taking part both after the final measurement is taken and once the project is fully completed.

Any person taking part in the monitoring aspect of the project should be aware that their physical data will be recorded and may bring up issues that the person themselves were not aware of. If this is found to occur, the athlete and only the athlete shall be informed regarding this.

As the information being collected will be completely anonymised it does not infringe on the Data Protection Act and if the specific person wishes for anything to be deleted at any time it will be done diligently.

Interviewees taking part in the study should be aware of ethical considerations whilst answering questions. If any questions, for instance, could tell of a new technology that has not been released or is in trial period the interview is encouraged not to disclose of said information.

Indicative Questions

I have outlined some indicative questions that will be asked to the chosen industry experts. For me to better equip my final stage analysis I feel that some of the answers will give great, and varied, insight into how people view these systems and if they are used to their highest potential. The questions are as follows:

1. Have you ever been involved in the development or use of an athlete monitoring system? Is yes, please provide a brief detail of the system.

2. Do you believe that monitoring an athlete's physical proficiencies could improve their abilities and performance? Please give a short reason for your answer.

3. Have you ever been predicted the occurrence of an injury in an athlete and it then happened? Please give a short reason for your answer.

4. Could long term physical analysis of an athlete pose any issues in the present or future in your opinion? Please give a short reason for your answer.

The questions asked are aimed to give opinions, critical analysis and potential pitfalls of an athlete centered monitoring system for use in training and injury prevention regimes. There will be no confidential questions asked and all answers will remain anonymous. The questions being asked will be the same for each industry expert. As seen above, there will be information required from each answer and not just a simple yes/no.

Please note that each question contained in the interview is entirely optional and you can feel free to omit any question that you do not wish to answer. With this, the researcher would be grateful if all questions are given an appropriate response.

Selection Process

Selection Process: Interviewees

I have decided to undertake a total of 6 industry expert interviews. These interviewees were selected due to their relevance to the subject of the dissertation and experience with athletes. They are also all familiar with the types of technologies being used within the research. The breakdown is as follows:

2 x Athletic Therapists
2 x Sports Scientists
2 x Elite Athlete Coaches

Selection Process: Athletes

Due to the variance of athletes in the modern sporting world, I am aiming my research across the board by coupling in various sporting areas. I believe this will give the research a better insight into an athlete's abilities whilst not hindering the results to a specific sport. In one instance, with regards to rugby union, I have decided to take two forwards and two backs as they are seen as very different athletes in terms of training and injury analysis. The breakdown is as follows.

2 x Senior Elite Hurlers
2 x Senior Elite Gaelic Footballers
2 x Senior Elite Rugby Union (Forwards)
2 x Senior Elite Rugby Union (Backs)

Overall, I believe that my selections for both industry expert analysis and specific athlete monitoring will give great insight into this area from different backgrounds.

C. Individual Athlete Results

Footballer 1	**Initial Measurements**	**After 29 Days**	**After 51 Days**	**After 76 Days**
Weight (kg)	82.6	83	83.8	84.2
Biceps (cm)	15.2	15.8	16.5	16.7
Triceps (cm)	7.2	7.3	7.8	8.2
Chest (cm)	102	102	104	104
Thigh (cm)	22	22.6	23.6	24.1
Calf (cm)	17.6	17.7	18.5	18.7
Combined Muscle Factor (cm)	164	165.4	170.4	171.7
Straight Leg Raise (R)	4	4	5	5
Straight Leg Raise (L)	3	4	4	4
Shoulder Mobility (R)	4	4	4	4
Shoulder Mobility (L)	4	5	5	5
Hip Flexor (R)	5	5	5	5
Hip Flexor (L)	5	4	4	5
Glute Bridge (R)	3	3	4	4
Glute Bridge (L)	4	4	4	4
Rotational Stability (R)	2	3	5	5
Rotational Stability (L)	1	3	4	5
Shoulder Lift Off	4	4	4	5
Trunk St. Press-Up	3	3	4	4
Lunge & Twist (R)	4	4	4	4
Lunge & Twist (L)	3	3	3	4
Hurdle Step (R)	3	3	3	4
Hurdle Step (L)	3	3	4	5
Squat	2	3	3	4
Injury Rehabilitation Level	N/A	N/A	N/A	N/A

Footballer 2	Initial Measurements	After 29 Days	After 51 Days	After 76 Days
Weight (kg)	76.6	77	77.1	77.3
Biceps (cm)	13.1	13.1	13.3	13.4
Triceps (cm)	6.8	6.8	7	7.1
Chest (cm)	91	93	93	93
Thigh (cm)	17	17.5	18.2	18.6
Calf (cm)	13.2	13.4	13.5	13.5
Combined Muscle Factor (cm)	141.1	143.8	145	145.6
Straight Leg Raise (R)	3	4	5	5
Straight Leg Raise (L)	3	4	4	4
Shoulder Mobility (R)	5	5	5	5
Shoulder Mobility (L)	5	5	5	5
Hip Flexor (R)	3	4	4	5
Hip Flexor (L)	5	5	5	5
Glute Bridge (R)	4	4	4	5
Glute Bridge (L)	3	4	4	4
Rotational Stability (R)	4	4	5	5
Rotational Stability (L)	5	5	5	5
Shoulder Lift Off	4	5	5	5
Trunk St. Press-Up	4	4	4	4
Lunge & Twist (R)	3	4	4	4
Lunge & Twist (L)	3	3	4	4
Hurdle Step (R)	2	3	4	5
Hurdle Step (L)	3	3	4	4
Squat	3	3	4	4
Injury Rehabilitation Level	N/A	N/A	N/A	N/A

Footballer 3	Initial Measurements	After 29 Days	After 53 Days	After 76 Days
Weight (kg)	78.6	78.6	78.4	78.5
Biceps (cm)	14.1	14.1	14.2	14.4
Triceps (cm)	7.4	7.5	7.5	7.5
Chest (cm)	98	98	98	98
Thigh (cm)	16	16.1	16.1	16.2
Calf (cm)	12.8	13	13.1	13.1
Combined Muscle Factor (cm)	148.3	148.7	148.9	149.2
Straight Leg Raise (R)	4	4	4	5
Straight Leg Raise (L)	4	4	4	4
Shoulder Mobility (R)	2	2	3	3
Shoulder Mobility (L)	2	2	2	3
Hip Flexor (R)	3	3	3	4
Hip Flexor (L)	3	4	4	5
Glute Bridge (R)	N/A	N/A	N/A	N/A
Glute Bridge (L)	N/A	N/A	N/A	N/A
Rotational Stability (R)	4	4	5	5
Rotational Stability (L)	5	5	5	5
Shoulder Lift Off	3	4	5	5
Trunk St. Press-Up	4	4	5	5
Lunge & Twist (R)	N/A	N/A	N/A	N/A
Lunge & Twist (L)	N/A	N/A	N/A	N/A
Hurdle Step (R)	2	3	3	3
Hurdle Step (L)	3	3	3	4
Squat	3	3	4	4
Injury Rehabilitation Level	0	1	4	2

Hurler 1	Initial Measurements	After 32 Days	After 55 Days	After 81 Days
Weight (kg)	83.1	83.1	83.5	83.4
Biceps (cm)	16.3	16.4	16.4	16.5
Triceps (cm)	8.5	8.5	8.6	8.8
Chest (cm)	101	101	102	102
Thigh (cm)	17.9	18.1	18.1	18.1
Calf (cm)	13.9	14	14	14.1
Combined Muscle Factor (cm)	157.6	158	159.1	159.5
Straight Leg Raise (R)	4	5	5	5
Straight Leg Raise (L)	5	5	5	5
Shoulder Mobility (R)	3	3	4	4
Shoulder Mobility (L)	4	4	4	5
Hip Flexor (R)	2	3	3	4
Hip Flexor (L)	2	3	3	3
Glute Bridge (R)	3	4	4	4
Glute Bridge (L)	1	2	3	4
Rotational Stability (R)	3	3	3	4
Rotational Stability (L)	4	4	4	4
Shoulder Lift Off	2	3	4	5
Trunk St. Press-Up	3	4	4	5
Lunge & Twist (R)	3	4	4	4
Lunge & Twist (L)	3	3	3	4
Hurdle Step (R)	4	4	4	5
Hurdle Step (L)	3	4	4	4
Squat	3	3	4	5
Injury Rehabilitation Level	N/A	N/A	N/A	N/A

Hurler 2	Initial Measurements	After 32 Days	After 55 Days	N/A
Weight (kg)	80.2	80.2	80.2	N/A
Biceps (cm)	17.2	17.3	17.7	N/A
Triceps (cm)	9.1	9.3	9.3	N/A
Chest (cm)	103	103	104	N/A
Thigh (cm)	18.5	18.9	19.2	N/A
Calf (cm)	14.1	14.6	14.7	N/A
Combined Muscle Factor (cm)	161.9	163.1	164.9	N/A
Straight Leg Raise (R)	1	2	3	N/A
Straight Leg Raise (L)	2	3	3	N/A
Shoulder Mobility (R)	4	4	4	N/A
Shoulder Mobility (L)	3	4	4	N/A
Hip Flexor (R)	3	4	4	N/A
Hip Flexor (L)	4	4	4	N/A
Glute Bridge (R)	3	3	4	N/A
Glute Bridge (L)	2	3	3	N/A
Rotational Stability (R)	1	1	3	N/A
Rotational Stability (L)	1	1	2	N/A
Shoulder Lift Off	3	3	3	N/A
Trunk St. Press-Up	4	5	5	N/A
Lunge & Twist (R)	4	4	5	N/A
Lunge & Twist (L)	3	4	5	N/A
Hurdle Step (R)	3	4	4	N/A
Hurdle Step (L)	3	4	5	N/A
Squat	3	4	4	N/A
Injury Rehabilitation Level	N/A	N/A	N/A	N/A

Hurler 3	Initial Measurements	After 32 Days	After 55 Days	After 81 Days
Weight (kg)	82.1	82.3	82.3	82.2
Biceps (cm)	15.9	15.9	16.1	16.6
Triceps (cm)	8.3	8.5	8.6	8.9
Chest (cm)	99	100	100	102
Thigh (cm)	17.4	17.9	18.4	19
Calf (cm)	13.9	14.4	14.5	14.9
Combined Muscle Factor (cm)	154.5	156.7	157.6	161.4
Straight Leg Raise (R)	3	4	5	5
Straight Leg Raise (L)	4	4	4	5
Shoulder Mobility (R)	4	4	4	4
Shoulder Mobility (L)	4	4	5	5
Hip Flexor (R)	5	5	5	5
Hip Flexor (L)	5	5	5	5
Glute Bridge (R)	4	5	5	5
Glute Bridge (L)	3	5	5	5
Rotational Stability (R)	3	4	4	5
Rotational Stability (L)	4	4	4	4
Shoulder Lift Off	3	4	5	5
Trunk St. Press-Up	2	3	3	4
Lunge & Twist (R)	3	4	5	5
Lunge & Twist (L)	3	4	4	5
Hurdle Step (R)	4	5	5	5
Hurdle Step (L)	5	5	5	5
Squat	4	4	4	5
Injury Rehabilitation Level	N/A	N/A	N/A	N/A

Rugby Player 1	Initial Measurements	After 30 Days	After 53 Days	After 80 Days
Weight (kg)	88.1	88.2	88.6	88.8
Biceps (cm)	16.3	16.9	17.8	18.1
Triceps (cm)	9.1	9.4	9.9	10.3
Chest (cm)	102	104	107	108
Thigh (cm)	18	18.3	19	19.4
Calf (cm)	14.2	14.4	14.8	15.2
Combined Muscle Factor (cm)	159.6	163	168.5	171
Straight Leg Raise (R)	2	3	3	4
Straight Leg Raise (L)	2	3	3	4
Shoulder Mobility (R)	3	4	4	4
Shoulder Mobility (L)	3	4	4	4
Hip Flexor (R)	3	3	3	4
Hip Flexor (L)	4	4	4	4
Glute Bridge (R)	3	4	4	5
Glute Bridge (L)	4	4	5	5
Rotational Stability (R)	5	5	5	5
Rotational Stability (L)	5	5	5	5
Shoulder Lift Off	4	4	4	5
Trunk St. Press-Up	3	3	3	4
Lunge & Twist (R)	3	4	4	4
Lunge & Twist (L)	3	4	4	5
Hurdle Step (R)	3	3	3	5
Hurdle Step (L)	4	4	4	5
Squat	4	5	5	5
Injury Rehabilitation Level	N/A	N/A	N/A	N/A

Rugby Player 2	Initial Measurements	After 30 Days	After 53 Days	After 80 Days
Weight (kg)	110	110	110	110
Biceps (cm)	19.5	19.5	19.7	19.7
Triceps (cm)	10.1	10.2	10.2	10.2
Chest (cm)	113	113	113	113
Thigh (cm)	24.4	24.5	24.5	24.5
Calf (cm)	17.1	17.1	17.2	17.2
Combined Muscle Factor (cm)	184.1	184.3	184.6	184.6
Straight Leg Raise (R)	4	4	4	5
Straight Leg Raise (L)	3	3	4	4
Shoulder Mobility (R)	3	3	3	4
Shoulder Mobility (L)	3	3	3	3
Hip Flexor (R)	3	4	4	4
Hip Flexor (L)	4	4	4	5
Glute Bridge (R)	3	3	3	5
Glute Bridge (L)	3	4	4	5
Rotational Stability (R)	2	3	3	4
Rotational Stability (L)	3	3	4	4
Shoulder Lift Off	1	2	2	3
Trunk St. Press-Up	3	4	4	4
Lunge & Twist (R)	3	4	5	5
Lunge & Twist (L)	4	5	5	5
Hurdle Step (R)	3	4	4	5
Hurdle Step (L)	4	4	5	5
Squat	5	5	5	5
Injury Rehabilitation Level	N/A	N/A	1	4

Rugby Player 3	Initial Measurements	After 30 Days	After 53 Days	After 80 Days
Weight (kg)	79.1	80.2	80.9	81.3
Biceps (cm)	15.2	15.7	16.1	17.7
Triceps (cm)	8.7	9.1	9.4	10.4
Chest (cm)	98	100	102	105
Thigh (cm)	17.4	17.8	18.4	19
Calf (cm)	13.1	13.3	13.6	14.1
Combined Muscle Factor (cm)	152.4	155.9	159.5	166.2
Straight Leg Raise (R)	4	5	5	5
Straight Leg Raise (L)	5	5	5	5
Shoulder Mobility (R)	4	4	4	5
Shoulder Mobility (L)	4	5	5	5
Hip Flexor (R)	4	4	4	4
Hip Flexor (L)	3	4	5	5
Glute Bridge (R)	3	3	4	5
Glute Bridge (L)	3	4	5	5
Rotational Stability (R)	4	4	4	5
Rotational Stability (L)	5	5	4	5
Shoulder Lift Off	4	5	5	5
Trunk St. Press-Up	3	3	4	4
Lunge & Twist (R)	4	4	5	5
Lunge & Twist (L)	3	3	4	4
Hurdle Step (R)	3	3	3	4
Hurdle Step (L)	3	4	4	4
Squat	4	4	5	5
Injury Rehabilitation Level	N/A	N/A	N/A	N/A

Rugby Player 4	Initial Measurements	After 30 Days	After 53 Days	After 80 Days
Weight (kg)	83.5	83.5	83.8	83.9
Biceps (cm)	16.1	16.2	16.2	16.4
Triceps (cm)	9.3	9.3	9.4	9.4
Chest (cm)	103	103	103	104
Thigh (cm)	19.3	19.4	19.4	19.4
Calf (cm)	14.4	14.4	14.4	14.4
Combined Muscle Factor (cm)	162.1	162.3	162.4	163.6
Straight Leg Raise (R)	3	3	4	4
Straight Leg Raise (L)	4	4	4	4
Shoulder Mobility (R)	1	2	4	4
Shoulder Mobility (L)	3	3	4	5
Hip Flexor (R)	3	4	4	5
Hip Flexor (L)	1	2	3	4
Glute Bridge (R)	4	4	5	5
Glute Bridge (L)	3	4	4	4
Rotational Stability (R)	5	5	5	5
Rotational Stability (L)	5	5	5	5
Shoulder Lift Off	3	5	5	5
Trunk St. Press-Up	4	4	4	5
Lunge & Twist (R)	4	5	5	5
Lunge & Twist (L)	4	4	5	5
Hurdle Step (R)	2	4	4	5
Hurdle Step (L)	3	5	5	5
Squat	4	5	5	5
Injury Rehabilitation Level	N/A	N/A	N/A	N/A