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Ethics, Nanotechnology and Elite Sport – The Need for a Precautionary Approach

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Thesis Summary

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Elite sport is a competitive industry, with athletes continuously striving for innovative ways to gain advantages over their competitors. The increasing impact of sport sciences over recent decades has contributed much to this ethos, and has recently been witnessed in the application of sports engineering, working to integrate new technologies in order to enhance levels of athletic performance and also athlete safety. The application of nanotechnology offers a sport engineer the potential to improve equipment used both in and out of competition. Nevertheless, despite its emerging integration into sports sciences, limited attention has been paid to the ethical impacts this technology may have on elite sport.

To address this problem, an eclectic normative approach is pursued, allowing for the range of nanotechnological application to elite sport to be considered, in order to generate critical ethical evaluations in relation to its current and potential use within elite sport. The issues were framed variously through consequentialist and deontological analysis. Three nanotechnological case studies are presented, highlighting potential benefits and disbenefits that nanotechnology may present, and to additionally determine whether, and if so, what, deontologically framed regulatory action were required to govern its use within elite sport. The first case study considered nanotechnology's application to the sport of road cycling; the second considered nanotechnology's application to performance analysis; and the third considered nanotechnology's application to horse race betting.

The analysis of the case studies revealed that nanotechnology presents a number of benefits for elite sport, such as improved levels of performance and enhanced safety; but also disbenefits, such as those relating to fairness and corruption. Despite this, it is argued that, at present, nanotechnology does not pose a significant risk to the integrity of sport. But in order to reduce any future risk, the disbenefits should be addressed. A case is consequently argued for the application of a weak version of the Precautionary Principle applied through an original ethical analytical tool, in order to govern the initial integration phase of nanotechnology. The work concludes by outlining more specific regulatory actions that could be taken in order to inform the development of a 'nano' specific regulatory framework, in order to govern nanotechnology's continued long term safe and ethical use within elite sport.

Declaration and Statements

Declaration

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed ....

Date ....

Statements

Statement One

This thesis is the result of my own investigations, except where otherwise stated.

Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

Signed ....

Date ....

Statement Two

I hereby give consent for my thesis, if accepted, to be available for photocopying and for inter-library loan, and for the title and summary to be made available to outside organisations.

Signed ....

Date ....

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Acknowledgements

For Mum, Dad, Lou, Charl, Isabel, Mike and Andrew:

Thank you for always believing in me.

I am enough.

Rob.

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- **Tables 2-4 are repeated in Chapter Eleven as a part of the Conclusion.**

Abbreviations

AFM	Atomic Force Microscope
BHA	British Horseracing Association
CNTS	Carbon Nanotubes
DNA	Deoxyribonucleic Acid
EC	European Commission
EPFL	European Professional Football Leagues
FIA	Fédération Internationale de l’ Automobile
FINA	Fédération Internationale De Natation
FFP	Financial Fair Play
ISEA	International Sports Engineering Association
IPC	International Paralympic Committee
ITF	International Tennis Federation
IOC	The International Olympic Committee
NFL	National Football League
NIN	National Institute for Nanotechnology
NNI	National Nanotechnology Initiative
PP	Precautionary Principle
SNP	Silica Nanoparticles
SPM	Scanning Probe Microscopes
STM	Scanning Tunneling Microscope
TPD	Total Performance Data
UCI	Union Cycliste Internationale
UEFA	Union of European Football Associations
UKAD	UK Anti-Doping

UNESCO	United Nations Educational, Scientific and Cultural Orgnainsation
USGA	United States Golf Association
WHO	World Health Organization
WPA	World Para Athletics

Chapter 1 - Introduction

1. The Emergence of Elite Sport

The term sport can be defined as an activity that is carried out for pleasure, and requires the need for physical effort or skills, often conducted in a specialized area in accordance to fixed rules (Hornby 2005). From this perspective, it could be argued that through one form or another; humans had already participated in sporting activities, yet its formal conception is generally believed to have occurred via the emergence of the first Olympiad in Ancient Greece; held between the 8th century B.C and the 4th century A.D (Bellis 2018; TOM 2013). This was initially a single day, later extended after 684 BC to three days, and then five in the 5th century BC (IOC 2019). Once more established, the Olympia proceeded to take place every four years, with athletes required to compete across a pentathlon of sports, including running, boxing, horse racing, and wrestling (Lambert 2017). All non-enslaved Greek males (women were not allowed to enter or even attend) were allowed to participate no matter what their background, with most being soldiers (IOC 2019). The winner of which would be awarded a crown made of olive leaves, signifying that they were the best and most worthy of athletes (Bellis 2018; Lambert 2017). This was a significant achievement for the athlete, as the games were considered a religious festival, with the winner viewed as honouring Zeus (IOC 2019). Thereafter, sport increasingly became more prevalent and organized within human society as demonstrated in the Roman era, where gladiators and chariot racers would compete (often to the death) in order to entertain the crowds, earning them financial and celebrity reward (Lambert 2017). Moreover, the variation of sporting activities grew during the middle ages, with people increasingly taking part in events such as wrestling, dice, hunting and jousting (Lambert 2017).

Despite such early developments, many would agree that the birth of what is recognised as modern sport to have occurred during the Victorian era, driven by the Industrial Revolution, and resulting in improved levels of transport, wages and available recreational time for those across the broad spectrum of society (Steen

2008: Atherton et al. 2016; McIntosh 1979). This consequently enabled the mass populace an opportunity to access sport, liberating them from their pre-industrial state (McIntosh 1979). A societal shift such as this raised the profile of sport, increasing its importance within society, as well as generating new levels of participation and spectatorship (Atherton 2016). Thereafter resulting in a number of 'firsts' within sport occurring, such as the first golf championship in 1857, and first football league season in 1888 (Steen 2008).

Sport therefore became considerably more organised and in an era where professionalism was on the rise, sport was no exception. This led to a rise in 'rational recreational sport', advancing sport from its previous chaotic state, to a far more organised undertaking, via the integration of rules and concepts of fair play (Perry 2017). This was driven by the rising middle classes, who did not want their workers participating in dangerous sports which could result in them being off work, impacting productivity (Perry 2017). Supported more so through the establishment of National Sporting Governing Bodies, who formulated codes of conducts for those taking part in each sport; in turn defining the key features of each sport, and implementing rules in which it should be conducted (Perry 2017). Again, further promoting sport as a more formal and professional domain.

Entering into the latter half of 19th Century, the evolution of sport became increasingly more prominent; driven by a number of factors, such as increased levels of sporting commercialization, the ever growing emergence of the sports betting industry, improved provisions for spectator sport, the changing philosophy of sport, and improved financial welfare/standards of living (Kyrylenko 2017). This resulted in a number of sports turning professional, such as Baseball (with the formation of the National League of Professional Baseball Clubs 1871) and American Football (with the formation of National Football League being in 1902) (Riess 2017), which not only boosted the popularity of sport, but also embedded its place within society. This is evident when considering the viewing figures of the Olympic Games in Rio, where 3.6 billion tuned in to watch the games of 2016, as well as the NFL Super bowl with 103.4 million tuning in for one game alone (Statistica 2018; CBS 2018). Increased popularity such as this has also resulted in sport becoming a highly lucrative industry. This can clearly be exemplified when considering the Premier

League, which during the periods of 2016-17, generated £3.3 billion in tax revenue, and contributed £7.6 billion to the UK economy alone (Hughes and Ziegler 2019).

The ever-increasing commercialization, financial investment and professionalism of sport have also been key to shaping its modern philosophy. Before the professional or elite era, sport was an amateur activity, motivated by values such as fair play and hard work, and supported by a philosophy of participation rather than winning (Atherton et al. 2016). Many amateur teams consisted of individuals who had no intention of pursuing sport as a career (as many wished to pursue careers in alternative industries), but rather took part for the sheer enjoyment and gentleman's sportsmanship (Townson 1997, cited in Laza, 2003). Additionally, the amateur sportsman saw no shame in defeat, as long as each person had committed their all to the endeavor, and played with honor (Townsend 1997, cited in Laza, 2003). For the amateur sportsman, participation and effort was considered of greater importance than winning, which was simply a satisfying outcome of doing one's best (Townsend 1997, cited in Laza, 2003). Yet this philosophy was soon challenged by the rise of professionalism within the Victorian era, as money increasingly entered into sport, winning became more important. This meant that 'winning' and 'success' became pivotal values, allowing athletes, teams, and organizations access to the benefits that a increasingly commercialized sports industry could offer - both in terms of financial return, celebrity status and sporting longevity (Atherton et al. 2016). The amateur athlete was therefore no longer able to compete with the professional athlete who took sport seriously and conducted sport as a full time undertaking; marking the emergence of a new philosophy of sport, one motivated by the importance of winning within an ever increasing results based industry (Day and Oldfield 2014; Townsend 1997, cited in Laza, 2003).

Despite this shift, many of the values promoted by the amateur have not been lost, with several still central to modern elite sport. The essential values promoted by amateur sport such as ethics, fair play, and honesty, are still replicated today and hold significant importance within the modern domain (WADA 2019). Helping to ensure that the integrity of professional sport is upheld; and that those victorious are so for the right reasons. Yet despite this, the importance of winning still holds greatest value due to elite sport and its drive as a results-based industry.

Consequently athletes, coaches, teams and organisations are continually searching for new methods of improving levels of performance, with the aim of gaining an edge over those within a given competition. Thereby increasing their chances of success, enabling them to access the rewards that winning can bring. There are many examples of how this is being executed within elite sport, such as the application of sports medicine and psychological conditioning. Yet one of increasing prominence, and the focus of this body of work, is that of sports engineering.

2. Research Context

The increasing integration of sports engineering has become a vital element of modern athletic success. Consequently, its application has resulted in significant progression being made within sport, not only for the individual athlete, but also the sporting system as a whole (Taha et al. 2013). Further, it has aided significant improvements in levels of athletic performance and safety both in and out of competition, whilst also making sport more entertaining and engaging for spectators.

Yet despite such progression, this increasingly symbiotic relationship has also generated significant ethical debate relating to role that technology should play within elite sport, and where the line between man and machine lies. This has consequently polarized views on sports engineering, and its subsequent role within the domain. There are many who support its use, arguing that its integration is pivotal to its future, protecting it from stagnation, ensuring its relevancy in the eyes of the modern spectator (James 2010). Additionally, arguments have also been generated to support its continued use on the grounds of improved levels of performance and safety, enabling athletes to reach new levels of success within a given sport; keeping sport interesting for the spectator by allowing the boundaries of sporting success to be continually pushed (James 2010; Bjerkile 2009). Some suggest that considering sports engineering as 'controversial' is an exaggeration, stating that there is little difference between its use and other techniques used to improve levels of performance such as advanced training methods, coaching, and sports medicine (Dorey 2012).

Consequently, there are those who hold opposing views in relation to this debate, stating that the increasing application of sports engineering is a challenge to the spirit of sport, devaluing its integrity and undermining its nature. This has generated uncertainty in the eyes of the spectator, who in the most part, wants to witness a competition that tests athletic strength and not that of the technology they are using (James 2010). There are also growing concerns relating to equality and fairness, where it is argued that success is being increasingly determined by an athlete's access to the best technology during a given competition, and not their own efforts and skills; consequently generating an unfair, and unequal playing field (Loland 2002; James 2010; PDD 2014). The athlete who wins may therefore not be the 'best', but the one with the greatest access to technological aids. Moreover, the application of sports engineering to elite sport has also exacerbated concerns relating to athletes becoming too dependent on new and emerging technologies for performance gains, resulting in potential deskilling, as well as reducing the level of challenge expected at the elite level (Miah 2006; James 2010).

The application of sports engineering to elite sport has generated significant debate, which is only likely to intensify as it continues to evolve as we look to the future. Consequently, it is likely there will be a number of transformative technologies integrated into elite sport soon that may offer the potential to significantly improve athletic performance beyond what is considered currently possible.

3. Research Focus

Nanotechnology is a new and emerging technology increasingly integrated into equipment used by athletes within elite sport, which demonstrates the transformative potential as discussed prior. This is due to its advantageous properties, which could offer benefits in relation to levels of performance and safety for the individual athlete, as well as the wider sporting industry (Verma 2013). A prime example of this can be seen in golf, where Carbon Nanotubes (CNTS from now on) have been applied to golf club shafts in order to increase the density and straightness of the club, helping a golfer to generate more power and distance when taking each shot (Nano 2017). In addition, CNTS are also being applied to other examples of sporting equipment such as tennis rackets; not only to improve racket strength, but also working to reduce weight - both essential attributes in supporting a tennis player reach their full potential within competition (NNIN 2006).

Due to its versatility as a technology, nanotechnology offers the potential to bridge all aspects of sports engineering, crossing the boundaries of both enabling and embedded technologies used at the elite level. An example of its application within embedded forms of sporting technology can be seen when considering its application in order to enhance existing biosensors (used to collect athlete biological data). This takes the form of the nanobiosensor, promoting advanced features, such as increased sensitivity and speed of data retrieval (Evans et al. 2016). In addition, providing essential benefits for athletes and coaches alike, used to improve athletic performance by allowing the construction of bespoke dietary plans and training methods, in turn boosting levels of performance and safety within elite sport.

To reflect, nanotechnology could potentially become a highly transformative technology within elite sport, further supporting athletes to reach their sporting potential and access new levels of success. Its integration could also help to reduce the chances of injury, essential to the long-term success of a modern athlete, as the longer they can stay fit, the more competitive they can be in a given sport. Such technology could work to further modernise elite sport in promoting its evolution as an industry.

4. The Problem Question

Despite nanotechnology's ever-increasing application to sporting equipment, there currently exists a knowledge gap in relation to how this technology may ethically impact elite sport, and whether its continued integration requires effective regulation. Within the available academic literature, there exists a clear lack of research available in relation to this issue, beyond that of the work conducted by Evans et al. (2016). The ethics of this technology has therefore already fallen behind that of its technological development; despite its ethical impacts being relatively unknown, and its integration already underway. This could potentially put the nature and integrity of sport at risk if not ethically considered and analysed. Hence, this knowledge gap must be addressed in order to determine how we should best continue with nanotechnology as it continues to evolve within elite sport.

In order to start addressing this problem I have identified the following research problem question:

What are the potential benefits and disbenefits of nanotechnology's integration into elite sport and does it require additional governance?

Answering this question will open discussion in relation to the potential ethical impacts this technology may have, and will begin to address the current knowledge gap existing within the academic literature.

5. Aims and Objectives

In order to establish an effective 'road map' to successfully answer this research problem question, it is essential to outline the key aims and objectives that will require addressing. These are as follows:

1. *To consider the potential ethical impact nanotechnology may have on elite sport.*
2. *To propose regulatory solutions in order to promote good governance practices in relation to nanotechnology's initial and potential future integration into elite sport.*

In order to meet these aims, the following objectives will be carried out:

1. *To review the impact sports engineering has already had on elite sport, by considering existing academic literature in order to establish key background information on the topic of sports engineering*

2. *To examine how and why sports engineers are looking to integrate nanotechnology into equipment used at the elite level*

3. *To conduct a review of nanotechnological case studies in order to determine its potential impact as a technology on elite sport*
4. *To examine and ethically evaluate the results of this review in order to determine solutions for its effective governance within elite sport*
5. *To recommend regulatory solutions based on the ethical evaluation conducted in the previous aim, promoting effective governance practices for nanotechnology's use in elite sport*

The completion of these aims will pave the way for the achievement of the key objectives, and subsequently inform and address the problem question established earlier in this chapter.

6. Research Value

This research can add considerable value to existing academic literature associated with the fields of sports engineering and ethics. There are many reasons for this, the first of which relates to the current and concerning lack of academic literature available in relation to the ethical impacts nanotechnology may have on elite sport. This research will start to address this issue, by providing original academic content.

Secondly, the discussions in relation to the potential impact nanotechnology may have on elite sport will also be vital in informing the establishment of any regulatory action that may be required to govern nanotechnology's application. Moreover, adding value to the field of sports engineering and the ethical regulation of new and emerging technologies, as at present, no such governance exists. Again, this research can therefore add originality to this field of study, by addressing and informing the existing knowledge gap.

The third way in which this research could add value is through its contribution of an original ethical decision-making tool in order to safely guide the integration of new and emerging 'nano' sporting technologies into sport. The use and application of a tool such as this would work to raise the profile of ethics within the world of sports engineering, ensuring that nanotechnology's technical and ethical progression would continue at the same pace; something which has not often been the case with integration of prior new technologies into the field. This would promote effective regulatory practices, along with the safety of the athlete and the sporting system as whole from any potential risks that nanotechnology may present. Conducting a 'pre-mortem[1]' of the potential issues that a new technology such as this may generate could help promote sporting bodies to deploy more informed and effective methods of regulation when faced with a given ethical issue in the future.

Finally, this work represents new and original research, not only to the fields of sport and ethics, but also engineering. Although it would be fair to say that there is an increasing body of work within the academic literature that considers how nanotechnology is (and could) be applied to sporting equipment, there currently exists a gap in the literature (as raised earlier in this chapter) in relation to the potential ethical impact this technology may have on elite sport, and how it should look to progress from a regulatory stand point. Hence, this body of work addresses a new area of ethical discussion and debate; something that has yet to be fully explored, and therefore adding value to existing knowledge relating to nanotechnology's application and use.

7. Thesis Overview

This research is comprised of eleven chapters, each of which considering a different aspect of study. In this first chapter, an overview of the thesis was provided, outlining the key research problem, aims/objectives and value as an original piece of research.

Chapter two offers a contextual review of the key literature relating to sports engineering. This chapter consists of three parts, the first of which considers the history of sports engineering, providing an overview of its development as a field over time. The second considers its application and categorization, drawing key distinctions between enabling and embedded forms of sporting technologies. Finally,

[1] A point expanded on later in this body of work.

the third presents a discussion in relation to the ethical benefits of sports engineering; considering key discussion points such as those relating to improved levels of performance, the promotion of sporting innovations, and increased levels of safety. This is followed by an additional ethical discussion relating to the disbenefits of sports engineering; which considers key discussions points such as concerns over the loss of sporting spirit, issues relating to fairness and equality, and the potential for the deskilling of elite athletes.

Chapter three establishes an essential knowledge foundation in relation to nanotechnology as a technology form. It considers key definitions (such as nanotechnology and nanomaterials), and provides examples of industrial applications of nanotechnology, including its present use within the fields of electronics and medicine for example. It then goes on to outline nanotechnology's current application to elite sport, such as its present use in sporting equipment, clothing and sporting venues.

Chapter four addresses research methodologies. It starts by outlining the main focal point of this research, which is to address the current lack of ethical analysis of nanotechnology's impact on elite sport. This knowledge gap is addressed through review and ethical analysis of three case studies. The first of which relates to nanotechnology's application to enabling equipment within the sport of cycling; the second considers the application of nanotechnology to embedded equipment within the field of performance analysis; and the third and final case study considers nanotechnology's application to a third party application in the form of sports betting. Each case study is presented alongside a justification, as well as any potential limitations; promoting balanced research practices. After this, a justification for an applied ethical approach is presented, underpinned by a generalised consequentialist judgment framework. Again, the benefits of a framework such as this, along with its limitations are presented, along with a final justification for its application in order to review the case studies. The chapter concludes by presenting the argument that although this work is one of mainly consequentialism, it does not reject deontological concepts. Therefore, in a similar manner to that of principlism within the field of bioethics, this work adopts what could be considered as a 'hybrid' applied ethical framework.

Chapters five, six and seven offer extensive ethical analysis of each of the case studies; firstly by putting them in context, and then by providing extensive ethical analysis of the potential benefits and disbenefits that each case study may present within their specific sporting contexts.

Chapter eight offers an analysis of the case study findings, considering how to best move forward with nanotechnology's use within elite sport. The discussion centres around findings from the ethical analysis of the case studies; whereby a case for the controlled progression of this technology within sport is outlined, determining that it is not a form of cheating or technology doping through the application of the International Paralympic Committee technological (IPC from now on) doping framework (WPA 2018). It concludes by advocating the continued use of nanotechnology at present within elite sport, but in a controlled and ethical manner; taking all relevant precautions in order to prevent the disbenefits also presented from becoming a reality.

The findings of chapter eight inform the decision in chapter nine to present a case for the application of the Precautionary Principle (abbreviated to PP) in order to govern nanotechnology's initial integration into elite sport. This chapter begins by providing historical context for the PP, drawing distinctions between the strong and weak versions of the principle. It later provides an in depth discussion in relation to the pros and cons of this form of regulation, concluding with a justification of its integration into an original ethical analytical tool in order to govern nanotechnology's initial application into elite sport.

Chapter ten argues a case for specific regulation to be established in order to effectively govern disbenefits generated by nanotechnology's use within elite sport. Consequently allowing for the PP within the analytical tool to be repealed, and a long-term nano specific regulatory framework to be established. This is conducted via careful consideration of the disbenefits raised through the ethical analysis of the case studies presented earlier in this work. The outcomes of which include calls to action such as standardisation, financial fair play and the application of secure date networks.

Conclusions are drawn in chapter eleven, offering a review of the work conducted in this research. It reiterates the key findings; that at present it would appear that the application and use of nanotechnology is not a threat to the integrity of elite sport, but that its use could offer a number of advantageous benefits. Yet despite this, it also presents a number of early warning signs and disbenefits in need of addressing. Consequently, a weak version of the PP is constructed in order to guide its initial integration, allowing time for more specific regulation to be established informing a specific 'nano' regulatory framework. After this, considerations of the research implications are made, identifying three key points. The first of which outlines that this body of work has started to address a significant knowledge gap that currently exists in relation to nanotechnology's potential ethical impact on elite sport. The second implication being that it has worked to establish regulatory procedures in order to govern nanotechnology's use within elite sport, firstly though the initial application of a weak version of the PP, then through the addition of more specific regulatory actions that could be used to inform the establishment of a specific 'nano' regulatory framework. The third and final implication (and arguably the most crucial) is the establishment of an original ethical analytical making tool to be used in order to determine a regulatory pathway for any 'nano' specific sporting equipment. This analytical tool is unique, and offers considerable originality to this topic and existing academic research. This chapter concludes by outlining a number of future implications of this research, offering methods of further evolution ranging from the use of an alternative ethical framework; alternative ethical review frameworks; increasing the number and depth of case studies; and finally, the completion of a potential retrospective review of the case studies.

Now that the purpose, value and outline of this research has been presented, the next chapter will provide a review of sport engineering; considering its purpose, origins, and impacts on elite sport. This will allow for a knowledge foundation to be established in order to underpin the rest of this research.

Chapter 2 - A Review of Sports Engineering

1. Introduction

Sports engineering has become an integral element to elite sport, offering athletes new and emerging technologies in order to increase their chances of success both in and out of competition. Beyond this, it has also had a considerable impact on the sporting system as a whole, promoting its evolution, alongside helping to prevent its stagnation. Consequently, a symbiotic relationship has been established between sports engineering and elite sport, and as we continue to progress into the future, this relationship is only likely to strengthen and intensify. Athletes, coaches and teams are progressively turning to this technology form in order to provide an edge over their competitors, increasing their potential chances of success in competition.

In order to understand how the two fields have become so interconnected, the start of this chapter will provide an overview of sports engineering; considering its origins and current place within elite sport. It will then progress on to consider the impact that sports engineering has had on elite sport, both in terms of sporting progression and its ethical benefits/disbenefits.

2. An Overview of Sports Engineering

Sports engineering is defined as the application of maths and physics to solve sporting problems by means of design, development and research into external devices (Taha et al. 2013). Examples of this may include the building of facilities, analysis of athletic performance using technology, and the development of coaching tools (Driscoll 2012).

Those who work within this field are known as sports engineers; their intention is to resolve challenges faced by a given athlete in terms of performance and safety, via the creation of new equipment based around their needs (Taha et al. 2013). To achieve this, sports engineers adopt a number of roles relating to design, testing and feedback of new equipment that is applied to the sporting environment (Driscoll 2012; Baine 2012). They regularly work across multiple disciplines within the sporting world, with the ambition of improving levels of performance and safety. This process often involves working within sub-disciplines such as: material engineering (which includes the development of new textile materials); computational modeling (which represents disciplines of complex systems, such as fluid dynamics); instrumentation (which involves sensors and electronic components, for example hawk eye in tennis); and finally design economics (which involves body mapping techniques to deliver maximum speed and efficiency to an athlete) (Taha et al. 2013). Once a new piece of equipment has been developed, sports engineers will then work directly with an athlete in order to adjust and improve the equipment in order to continually promote technological improvements in relation to performance and safety. Furthermore, to ensure that any new technology complies with a sport's regulatory procedures, engineers are also working closely with governance bodies; ensuring the safe and ethical integration of this technology for athletic use (HDRISCOLL 2012).

3. Catergorisation of Sports Engineering

Equipment used in sports engineering can be categorised into two distinct groups, enabling and embedded technologies (Bhania, 2012). Each utilises the most up to date scientific disciplines, including material engineering, computational modeling, instrumentation, and design/ergonomics in order to develop the best and most effective equipment for athletic use (Taha 2013).

Enabling technologies are those that are used by athletes in order to compete (Bhania 2012). This equipment is vital to athletic success, and regularly undergoes scrutiny through dedicated prototyping and experimentation to ensure it offers an athlete the greatest benefits in relation to performance and safety. There are many examples of enabling technologies, but one of specific prominence is that of the golf ball. These have been re-engineered many times, with new materials regularly introduced into its design and construction, helping to increase the flight and accuracy of a golfers shot. This can be shown when considering the 1950s, where golf balls had a smooth surface area, as it was thought that such a design produced the greatest flight time (Haake 2012). However, it soon became apparent through observation that the older balls that had accumulated more nicks and bumps, actually travelled further than those with a smooth surface (Haake 2012). After further research, it became apparent that the roughness of the surface actually generated turbulence in the layer of air in contact with the ball, working to stabilize the encompassing air flow, whilst also reducing the drag; allowing for a greater flight length in comparison to the smoother surface balls (Haake 2012). This new understanding of golf ball design via scientific analysis resulted in the emergence of the dimpled ball, which is now in dominant use within the sport.

Another example of an enabling technology includes the tennis racket; over the years this essential form of sporting equipment has undergone significant evolution, modified in order to support a player improve their level of performance. Modern tennis rackets have come a long way since their introduction over a century ago; with the very first versions being made in 1874 in London by Major Wingfield, constructed from solid wood (Gandu 2012). This racket had a number of drawbacks including a small head, heavy weight, cumbersome nature, and lack of power. In 1967 the Wilson Sporting Goods Company introduced the metal racket (T2000), which was stronger and lighter than its previous wood counterpart, and soon became dominant within the sport (Cooper 2017). Although this racket was a significant improvement, it still had its limitations, particularly in relation to its head size, which remained small. This was later addressed via another redesign in 1976, where Howard Head, then working for Prince, introduced the first aluminum-oversized racket, which soon gained popularity - the Prince Classic (Cooper 2017; Gandu 2012). This brought with it a number of benefits, such as an increased ability for a player to generate power from each of their shots. However much like its predecessors, issues remained, as hard off center shots would distort the aluminum frame, changing the direction in which the string plane was facing. This resulted in unpredictable shots, proving disadvantageous for an elite player (Cooper 2017; Gandu 2012). Consequently, another redesign took place by sports engineers to resolve this problem; incorporating composite materials such as graphite in order to make the racket a lot stiffer and lighter, which in turn improved player's control over the ball (Cooper 2017). These rackets are now commonplace at all levels within the sport, and are a testament to how much one piece of equipment has changed since its humble beginnings.

In contrast, embedded technologies are those that work behind the scenes, supporting an athlete both in and out of competition via performance analysis methods (Bhania 2012, p.21). These technologies allow coaches, athletes and other stakeholders the potential to analyze an athlete's movements (and more recently, biological function) in order to promote improvements in performance levels and safety (IME 2012; ASME 2011). This is achieved via the application of technological monitoring systems to an athlete that are able to track and feedback on an athlete's performance levels to coaches; often through instrumentation disciplines, essential for the development of training programmes promoting continuous athletic enhancement (IME 2012). Again, there are many examples of such technologies; one of which being motion capture cameras, which provide coaches with the ability to analyze an athletes' physical condition, as well as performance and technical skill, with the aim of improving performance levels and decreasing the chances of injury through poor technique (Pueo and Olmedo 2017). There are traditionally two methods of analysing human movement, the first is a video-based approach, where an athlete is recorded during training sessions with the footage then later analyzed via coaching teams and software systems as soon as the task or digitising is complete (Pueo 2016). The second is an automatic tracking motion analysis system, which tracks and records an athlete’s motion in real time without a delayed digitisation process (Pueo 2016; Lopez et.ao 2017). These systems involve a variety of motion capturing techniques, from multiple video cameras, to single camera systems with additional sensors to retrieve more in depth information (Liebermann et al. 2017). Embedded technology such as this have become an essential aspect of training in almost every sport, with the video data gained becoming vital to the improvement of sporting techniques and training methods. There are a number of sports that utilise such technology, including basketball, as this allows athletes and coaches to review the footage of a player's performance, in order to identify areas of strength and weakness to further improve their technique both on and off the court (Yucesir 2003). For example, if an athlete is not completing a jump shot effectively, video footage can be reviewed, and coaches can suggest methods in which a player's technique can be improved in order to enhance their point scoring ability.

Another example of this technology is gait and motion analysis, which monitors an athlete's run or walk, providing data on weight distribution and other lower limb biological movement (Shukla 2010). This data can suggest ways in which an athlete can alter their running style and walking technique, not only as a preventive measure to reduce injuries, but also as a method of improving performance. For example, if an athlete is able to improve their running technique, there is a good chance that this will aid their performance by increasing their efficiency within competition (Shukla 2010).

However, as this technology has progressed and become more sophisticated, newer forms of embedded technology have emerged in the field, allowing for a more sophisticated approach to the monitoring of an athlete's performance and safety. One particular example is the PlayerTek vest, which houses 'The Pod', a data collection GPS tracker that logs an athletes movements, such as the number of sprints they have carried out along with the distance that they have covered throughout a given competition or game (Nield 2018). This device is predominately used within the sport of football at all levels, allowing coaches along with the player themselves to monitor their performance levels throughout a match, in order to identify their strengths and weaknesses whilst on and off the pitch. In addition, there are also biological tracking sensors emerging within this field of sports engineering known as biosensors. Athletes wear these sensors whilst training and competing, in order for biological data to be collected that can then be sent off to labs in order to provide feedback on their biological function (QMUL 2011). This data allows for a biochemical profile of an athlete to be developed, which in turn provides coaches greater insight into an athlete’s bodily function; allowing for more bespoke training and dietary plans to be created, again in order to improve athletes’ levels of performance and safety.

Each of the technologies developed via sports engineering are currently regulated by each sports individual governing body (IME 2012). For example, in Tennis, the International Tennis Federation (ITF) conducts regulation of new technologies both in relation to enabling and embedded, whereas in Swimming it is conducted by the Fédération Internationale De Natation (FINA) (FINA n.d.; ITF n.d.). It is therefore their role to weigh up the benefits and disbenefits of each new technology introduced into a given sport, to determine whether it represents a form of progress, or indeed a threat to the integrity of the sport.

4. The Origins of Sports Engineering

The term 'sports engineering' was first coined in the 1990's, but its history predates this, going back at least three centuries, attributed to those such as Sir Isaac Newton and Lord Rayleigh (1877) (Taha et al. 2013; Fara 2013). Yet it was not until the Industrial Revolution where sports engineering saw a particular growth in the field, driven by the emergence of new manufacturing techniques, which in turn enabled the creation of new sporting equipment and cheaper standardised sporting equipment (Bhania et al. 2012). Sport consequently moved away from merely being a game that was championed by the physically dominant, as the new and increased availability of equipment allowed for sport to become more accessible to the masses. Furthermore, due to increased manufacturing scales of sporting equipment driving ever-increasing revenues for owners, manufactures took more risks. They would increasingly experiment with different designs and materials in order to continue to improve on a given product that was created (Bhania et al. 2012; Taha et al. 2013).

After the Second World War, innovations in sports engineering continued to progress with greater velocity, with discoveries within the field occurring more regularly such as that of carbon fibre in 1958 (ACS 2018). A material, which has been essential in transforming modern sporting equipment design; allowing for the creation of light weight and strong composite materials that could be applied to a range of equipment (ACS 2018). As time progressed, so did sports engineering; where elite sport began to integrate new and innovative sporting innovations, such as the 1968 Mexico City Olympics which saw the introduction of the first all-weather 'Tartan' running track. As well as the 1988 Seoul summer Olympics and Calgary Winter Olympics, whereby the first computerized time keeping system was implemented (Bahania et al. 2012; Taha et al. 2013).

The world of sport was therefore embracing engineering and science, not only to improve the individual athlete's performance levels and safety, but also sport as a whole. In the late 19th century, the International Sports Engineering Association (ISEA) was established, with the aim of overseeing the development of engineering in sport (Taha 2013). From this point on, sports engineering was recognised as a field in its own right, with sports engineers evolving their disciplines at a seemingly faster rate, resulting in the emergence of an increasing number of technological innovations. A prime example of this can be seen when considering the emergence of the Speedo LZR Race swimsuits in 2008 that were made from 100% polyurethane, and the S-Works Venge bicycle made from a single piece of carbon fibre (Morrison 2012ab; Radley 2018). Hence, it is clear that throughout the history of sport, engineering has played a pivotal role in its development, and is likely to continue as we enter into the future.

5. The Impact of Sports Engineering

Sports engineering is now a well-established and essential element of modern elite sport, yet despite the benefits that it has brought to the sporting world, its application has also raised a number of disbenefits, with some arguing that it has blurred the lines between man and machine. This section will consider this ethical debate, via consideration of the points outlined in the table below:

Table 1: The benefits and disbenefits of sports engineering's use in elite sport

Benefits	Disbenefits
Increased levels of performance	**Challenges to the spirit of sport**
Promotion of sporting innovation and spectator enjoyment	**Concerns relating to equality and fairness in competition**
Improved levels of safety	**Deskilling of athletes**

6. The Benefits

6.1 Increased Levels of Performance

Since its introduction into elite sport, sports engineering has supported athletes in reaching new levels of performance both in and out of competition. This has resulted in the limits of sporting achievement being continually pushed, with each generation of athlete regularly surpassing the attainment levels of the last. Haake's (2009) research into Olympic sports offers us a considerable insight into the correlation between sports engineering and improved performance levels. Through this work, Haake (Haake 2000/2009, pp.1427/1428; IM2 2012) generated a performance improvement index, identifying that sports engineering has had a positive impact on performance in relation to the sports outlined below:

- *100m sprint: 24% improvement over 108 years*
- *Pole vault: 86% improvement over 94 years*
- *Javelin: 95% improvement over 76 years*
- *1hr cycling record: 221% improvement over 11 years* (IME 2012, p.4)

It could however be argued that such improvements are not solely due to sports engineering, but other factors such as improved training methods, nutrition and coaching. Haake (2009, p.1431) considered this objection, and through the application of the performance index, he identified the performance improvements that were a direct result of the integration of sports engineering. In sprinting for example, of the 24% improvement, only 4% was linked with technological innovation such as ‘tighter, aerodynamic clothing’ (Haake 2009, p.1431). While developments in sports engineering in the pole vault and javelin saw improvements of around 30% (IME 2012, p.4). Interestingly, cycling saw the greatest increase in performance, particularly in relation to the one-hour race, with a 220% improvement over 102 years, with 101% of that being directly due to sports engineering (Haake 2009). Therefore, it is clear that technological innovation and engineering has had a direct impact on sporting performance levels.

Sports innovators would argue that technological developments such as those above that aid performance should in fact be celebrated, and not berated. This is because such changes are essential in helping athletes overcome 'gratuitous difficulties' within sport, and therefore should be embraced as the kind of rationality that sport encourages, resulting from a constant drive to improve levels of performance (Hardman 2014).

6.2 Promotion of Sporting Innovation

Sports engineering is argued to be essential in ensuring a sport continues to be innovative and relevant, by keeping it 'fresh', not only to those stakeholders involved in sport, but also the spectator. Furthermore, technological innovation brought about by sports engineering has also led to the emergence of new sports, such as snowboarding from skiing for example, allowing for the emergence of a new range of athletes and spectators (James 2010). Sports engineering could therefore be seen as an essential element to modern elite sport, and opposition to it could limit sporting evolution; resulting in stagnation, and the loss of spectatorship (NC 2014). This is because as a society we expect to see progress, and if a sport is not doing this and starts to stagnate, it becomes less popular, which could in turn impact its potential longevity (IME 2012). In addition, taking away new advancements in technology may remove the motivation for conducting new research into a given sport, as well as reducing investment. Manufacturers may see little point in offering significant revenue into sports engineering just for the resulting technology to be banned or curtailed (James 2010). A key element to the success of any modern sport is to ensure its continued popularity, and the development and evolution of new technology is essential in achieving this, promoting continued interest, and making it more accessible to prospective participants (Miah 2006).

Therefore, as technology goes through an evolutionary process, so does sport, working to keep it interesting and relevant for all those involved. Sports engineering has also given rise to a number of key breakthroughs in health and wellbeing, that goes beyond the world of elite sport, adding value to society as a whole. For example, portable wellbeing trackers originally designed for use at the elite level are now being used to combat childhood obesity, as they enhance the experience of sport for children (IME 2012).

6.3. Improved Levels of Safety

In addition to progressing levels of performance and spectator enjoyment, the evolution of sports engineering has also been a significant driving force behind the development of safety in sport. To examplify this, Bjerkile (2009, para.5) considered such safety developments within the sport of fencing:

> *Safety has clearly been the force behind improvements in fencing technology. Epee and foil weapons must now be made from merging steel, a jet-fighter alloy that is stronger and less brittle than conventional carbon steel, according to Dan DeChaine, armorer for the 1992 U.S Olympic team and member of the technical commission for the international fencing federation. The most dangerous situations in fencing arise when blades break in the heat of competitions and puncture fencer's protective garments. While 50 to 100 carbon blades typically snap in a world-class meet, only 3 steel blades broke in the last world championship.*

Bjerkile (2009) also argues that sports engineering has promoted more stringent safety standards for clothes used in elite sport. For example Fencing jackets are now made of Kevlar, and the mask constructed of stainless steel with a stronger mesh that can withstand puncture tests (Bkerkille 2009, para.6). This has made the sport safer, and has dramatically reduced the potential for injury, particularly through puncture wounds.

Another sport that has seen improved levels of safety as a result of sports engineering is American Football, with particular reference to the helmet. This piece of equipment has undergone dramatic change in recent years, particularly in relation to the materials that they are constructed from, shifting from leather to advanced plastics. The idea behind this design change was to reduce the potential risk of head injury, which it has achieved; setting a new standard of safety within in the sport, resulting in the complete replacement of leather helmets to plastic counterparts by the 1950s (Gelberg 1995).

Moreover, as we have entered into a modern era of elite sport, and as technology has continued to evolve and progress, levels of safety have also seen considerable advancement in recent years. In-keeping with the previous example of American Football, there has been a considerable improvement in relation to the safety of the sport due to an ever-growing demand to protect players in a domain that is increasingly physical, particularly in relation to head injuries. Yet despite the alterations that have had been made in relation to the construction of helmets, the physicality of the game has heightened, leaving a number of players with serious concussion issues due to significant collisions (McMahan 2018). The sport has responded by implementing (like other sports) a concussion protocol, working to promote player safety (McMahan 2018). The implementation of technology seeks to promote this protocol further, with new helmets (along with new trials with mouth guards) fitted with advanced sensors that measure the acceleration, location, direction and severity of a hit, again allowing for data to be sent to handheld devices located on the sidelines, which in turn enable trainers and coaching staff to check the safety of an athlete at all times - or remove the player from the game if necessary to undergo concussion protocol (Lemire 2018).

Athletes, coaches and organisations have also started to deploy the use of 'smart wearable’s' to track an athlete's biological levels during competitions and training sessions. Devices such as this offer data in regard to an athlete’s biological function; allowing coaching staff to make informed decisions as to whether an athlete is potentially at risk of injury. For example, the Zephyr wearable platform (a compression vest) is able to monitor six key inputs, including heart rate, breathing rate and heart rate variability (Sanyal 2018). Thus, if an athlete were training in intense heat (for example), the system would identify any particular stress on the athlete’s body, allowing for interventions to take place in order to protect the athletes from potential risk. This is just one of many examples of ways in which technology is now being used on a day-to-day bases in sport in order to protect the interests and safety of a given athlete.

Consequently it would be fair to say that sports engineering in recent years has become pivotal to ensuring the ongoing safety of an elite athlete, and as the technology continues to advance, is likely to become increasingly more pivotal; helping to ensure that athletes remain safe as they continue to progress, becoming faster and stronger.

7. The Disbenefits

7.1 A Challenge to The Spirit of Sport

A growing concern relating to the integration of sports engineering to elite sport is that it represents a potential challenge to the spirit of sport, and could therefore undermine its integrity. Before considering this argument, it is first essential to outline what the spirit of sport means. According to the World Anti-Doping Agency (WADA from now) *Anti-Doping Code 2021* (2019, p.10), it is defined by the following key values:

1. *Health*
2. *Ethics, fair play and honesty*
3. *Athletes' rights as set forth in the Code*
4. *Excellence performance*
5. *Character and Education*
6. *Fun and joy*
7. *Teamwork*
8. *Dedication and commitment*
9. *Respect for rules and laws*
10. *Respect for self and other Participants*
11. *Courage*
12. *Community and solidarity*

The concern is that sports engineering conflicts with these values, and removes the dedication and commitment required to be considered as an elite athlete. With ever increasing technological advancement, the line between the role of the athlete and that of the 'machine' has become increasingly more blurred. It could therefore be argued that technological advancement driven by sports engineering actually devalues sporting performance, as some hold the view that technologically aided performances require less work (James 2010). Furthermore, an athlete's increasing reliance on technology could also result in them becoming less responsible for their own sporting success, particularly in the eyes of the spectator (James 2010). An example of this can be demonstrated through consideration of Speedo's LZR Racer suit worn by swimmers during the Beijing Olympics, which promoted greater levels of aerodynamics by trapping air around the swimmer; consequently, aiding buoyancy, allowing for an athlete to glide through the water more easily (PDD 2012). This resulted in the athletes who wore this suit breaking records, as it helped enhance their performance levels beyond what could be naturally gained, and thus was subsequently banned, with FINA arguing that it devalued the spirit of the sport, considered a form of 'technology doping' (PDD 2012).

Another example can also be seen when considering cycling, which has long battled issues between technological advancement and its spirit as a sport. So much so that the Union Cycliste Internationale (UCI) has actually deployed extensive measures to ensure that the spirit of their sport is maintained through the deployment of the Lugano Charter (1996). This Charter was mainly developed in response to the influx of new super bikes to major competitions, which started to challenge the traditions of the sport, and alter the image of what people viewed as the cycle bike. As a result, the UCI worried that athletes and their teams would soon lose sight of the nature and purpose of the sport, relying too much on the technology, rather than the developing their own talents (WADA 2019). This is clearly stated in the Lugano Charter (UCI 1996, para.3/4):

> *The bicycle is also a historical phenomenon, and it is this history that underpins the whole culture behind the technical object. If we forget that the technology used is subordinate to the project itself, and not the reverse, we cross the line beyond which technology takes hold of the system and seeks to impose its own logic……………. The performance achieved depends more on the form of the man-machine ensemble than the physical qualities of the rider, and this goes against the very meaning of the cycle sport.*

Both examples therefore demonstrate how sports engineering could represent a challenge to the spirit of sport, and blur the lines between what is considered the strengths of the athlete and that of the technology.

7.2 Issues Relating to Equality and Fairness

In elite sport there exits economic gaps between teams and athletes, which consequently offer some an edge due to financial disparity. This has in some cases generated an unfair advantage in competition, highlighting a lack of equality throughout elite sport. Teams, coaches and athletes with greater access to funding have an increased chance of success in a given sport, which can be seen when considering Olympic achievements. A clear relationship between a nation's medal position and their gross domestic product/spend can be seen, with countries such as America and China regularly topping the rankings (James 2010).

Lack of access to modern technologies, mostly due to lack of financial support, also generates an equality and fairness barrier for emerging athletes within the domain who are hoping to progress and be successful in competition (James 2010). This has resulted in a gap between the 'haves' and the 'have not's', with those athletes who find themselves in the 'have not' category regularly behind the curve, no matter what their natural ability or how hard they train or develop their skillset (Levitan 2008). This could therefore be argued as a natural lack of equality built into sport, and unless all equipment is standardized, this inequality will continue to persist (Loland 2006). Consequently, if athletes do not have access to the same equipment, a competition could be seen as unfair, as the technology could provide a greater advantage to those who have it over those who do not (Dorey 2012).

Harris (2012) reiterates this point by considering Paralympic sport, where he argues that sports engineering has influenced success outcomes. He notes that some of the more successful teams are the ones who spend the most money on technological innovation, explaining that UK Sport has spent £700,000 on science and engineering over the last 4 years to improve athletic outcomes in competitions; money which is simply not available in other countries to do the same, generating an unequal playing field (Harris 2012, para.3). Hence, this is one of the major contributing factors to why almost all major international competitions are dominated by countries with money to spend on facilities, competition structures, and advanced research programmes (Harris 2012). However a conflicting argument could be made at this point, that that financial position/support of an athlete does not necessarily determine the outcome of a competition, as many other factors are required for success. Although a valid point, it would still be hard to disprove the clear link between cutting edge technologies and improved levels of success, which has in turn generated concerns relating to fairness and equality within elite sport (Harris 2012).

7.3 Deskilling of Athletes

There are growing concerns that the application of sports engineering to elite sport is working to deskill athletes, generating a greater reliance on technology for their performance success. This is a controversial issue, as the perceived deskilling of an athlete within a sport can generate negative perceptions. Sport is seen as fundamentally a human endeavor, where sporting performances are achieved by hard work and the development of an expert level of skill in order to compete and win at an elite level (James 2010). Consequently, the application of technology with the view of improving athletic performance by making life 'easier' for the athletes could be seen as damaging the 'internal goods' of a sport (James 2010). The success of an athlete could therefore be considered as a demonstration of the strengths of the technology, rather than the athlete's skill level.

An example of deskilling such as this can be seen when considering the case study of U-groove golf clubs, which were designed to promote significantly more spin than V-shaped grooves in other wedges and irons (Stachura 2007). The PGA subsequently banned the use of these clubs, as it was felt that they acted to deskill the golfer, and removed their own ability to generate spin (Stachura 2007; Miah 2006). The step taken to ban this type of club was supported by the players themselves, as they also considered such clubs to be offering an advantage by generating a higher spin rate; consequently improved ball control, and increasing a golfers performance levels without them having to earn such improvements (Garner 1989). Golfers felt that the clubs devalued the skill of game, which would not be good for the future of the sport (Gardner 1989). A second example of deskilling within the field can be seen when considering the application of the Polara golf ball to the sport. This was developed in the 1970s by two non-golfing scientists, and was designed with an odd dimple pattern, helping to reduce flight deviation (and a golfer's error) resulting from sliced or hooked shots (Hardman 2014). The ball soon became one of great debate within the golfing world, and was vastly disliked by traditionalists within the sport, who argued that it removed the challenge of the game and deskilled the players making the sport easier; undermining the sport particularly at the elite level where incredibly high levels of skill are a basic requirement (Hardman 2014). This resulted in the ball being banned by the United States Golf Association (USGA) in 1981, with a $1.4 million settlement stopping its sale [2] (Hardman 2014). Therefore whilst sporting technologies such as this could be seen as useful for a

[2] A new company has since acquired this golf ball technology in 2005, and through marking their ball strategically as 'training device' for amateur players, have circumvented the USGA rule, resulting in a renewed surge in use (Hardman 2014).

novice, and promoting the fun and enjoyment of a sport; at the elite level, technological application must be properly considered.

The application of technological innovation to elite sport has also raised issues relating to performance comparisons, as some argue that technology has enabled athletes to surpass records set by previous masters with relative ease, without having to develop the same level of skill required in the past (James 2010). This can be exemplified when considering Eliud Kipchoge, the first person to run a 26.2-mile marathon in under two hours (Burfort 2019). Although an incredible feat of athletic achievement, questions have since been raised relating to the technology used to support him in breaking this record. A particular focus has been on his footwear, a Nike Vaporfly prototype called the *Alphafly*, which features thick soles and carbon plates which act like springs (Hodgetts 2020). Although perfectly legal, an initial study conducted by the Journal of Sports Medicine in 2017 suggested that the Nike Vaporfly (such as those worn by Kipchoge) boosted running economy by 4% (later confirmed by a New York Times study in 2018) in comparison to trainers produced by other leading brands such as Adidas (Hodgetts 2020, para.7). Further, since the introduction of the Nike Vaporfly, the five fastest marathon times have been set by men wearing a form of these trainers (Burfoot 2019). Consequently this model of trainer, although certainly not the only reason for Kipchoges' success (as he is clearly an exceptional talent) could certainty have given him a potential x-factor which runners in the past (who were arguably as talented) did not have access to, generating unfair performance comparisons. It could therefore be argued that Kipchoge is no better than past running masters, but has access to more advanced technologies, enhancing his level of performance. The application of this technology to elite sport could further be argued to not only be disrespectful to previous masters of a sport, but acting against sporting traditions (James 2010). A point is similarly raised by Carr (2008), who argues that the role of sports engineering is to support the development of an athlete, but not remove the need to develop key skills that are essential for success in sport; as this would be inconsistent with the point or purpose of play, and devalue past successes.

The integration of sports engineering has therefore generated significant debate in recent years, with some regarding its integration as essential for sports' continued evolution, whilst others suggest that although such evolution is important, it must not come at the cost of sporting integrity, and that the focus of any competition should be the athlete, their efforts and skill. This debate is only likely to further intensify as sports engineers continue to look for increasingly more advanced technology forms in order to offer coaches, athletes and teams an edge over their competitors.

8. Conclusion

The integration of sports engineering has had a significant impact on elite sport, via promotion of its improvements in relation to athletic performance, safety and the sporting system as a whole (Taha et al. 2013). This has given rise to two categories of sports engineering; the first of which is enabling technology and the second being embedded technology, both offering the potential to improve levels of performance and safety within sport (Bhania, 2012). Examples of enabling technologies include those such as tennis rackets, and embedded technologies such as automatic tracking analysis systems (Cooper 2017; Pueo 2016; Lopez et.ao 2017).

Yet despite the emergence of sports engineering which has generated benefits relating to improved performance and safety levels there have also been a number of disbenefits raised (James 2010; Evans et al. 2016; Loland 2006). Concerns regarding the deskilling of athletes and issues relating to equality and fairness have become commonplace, and some argue are blurring the lines between the role of the athlete and that of the technology (James 2010; Loland 2006).

The debate relating to sports engineering is only likely to intensify as we enter into the future, as sports engineering and technology continues to progress; an example of prominence within this research being that of nanotechnology. However, before discussing the potential ethical impact that this technology may have on elite sport, it is first essential to establish a knowledge foundation in relation to this technology.

Chapter 3 - Nanotechnology and Elite Sport

1. Introduction

It is clear from chapter two that sports engineering has become an essential element to modern elite sport. Moreover, the emergence and development of key enabling and embedded technologies have become vital tools in supporting athletes, providing them with an edge over their competitors both in and out of competition. This has promoted greater levels of attainment within professional sport, pushing the boundaries of achievement beyond what has been previously thought possible.

However, in order for this progression to continue, sports engineers are required to explore new and emerging technologies, along with new design and material techniques in order to improve existing sporting equipment and systems. An example of this can be seen when considering their recent focus on nanotechnology. Due to its advantageous properties, it is already presenting the potential to be a transformative technology, and is able to cross the boundaries of sports engineering, making it a highly versatile technology form.

This chapter will therefore aim to provide essential background information in relation to nanotechnology as a technology form by providing key definitions, exploring its origins, and considering how and why sports engineers are looking to apply it as a technology to sporting equipment.

2. Key Terminology - Nanotechnology and Nanomaterials

There are numerous definitions of nanotechnology, but a commonly accepted version refers to it as science, engineering and a technology that is conducted at the nanoscale - 1 nanometer and 100 nanometers in size (EPA 2007; Boysen 2015; NNI 2019, para.1). Nanotechnology therefore refers to the use of materials, structures, devices/systems that are unique due to their properties, and include technologies that enable the control of the materials at the nanoscale (Allhoff et al. 2010). These materials are referred to as nanomaterials. Much like nanotechnology, there are many differing definitions for materials such as this, but a prominent example can be taken from the European Commission (2011, p.275) that defines a nanomaterial as follows:

> *A natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range of 1nm-100nm.*

Materials on the nanoscale occur in two forms, natural and engineered (EC 2011; Boysen 2015). Those that occur naturally include examples such as volcanic ash and soot, which are created incidentally, often through combustion processes and are sometimes known as ‘ultra fine particles’ (SafeNano n.d.). In contrast, those that are engineered are created through the process of nanomanufacturing, and are purposefully designed to be at the nanoscale (SafeNano n.d.; Wang n.d.). These engineered nano particles come in various shapes and sizes; for example if a nanomaterial has two dimensions that are lower than a few hundred nanometers, then they are considered as nanotubes or wires, and if a nanomaterial has only one dimension that is lower than a few hundred nanometers, it is considered to be a nanofilm (Schaming and Remita 2015). Engineered nanomaterials such as these offer a number of advantageous properties; such as their incredibly small size, excellent heat/electricity conductivity, and their ability to kill bacteria (Europa 2009). Consequently, they have become highly desirable to many industries, ranging from electronics, sports and health care.

A specific example of a nanomaterial is that of graphene, which is two-dimensional, only an atom thick, and takes the form of a flat lattice of hexagons linked in a honeycomb pattern (Colapinto 2014). Each layer consists of hexagonal rings of carbon, which requires about three million layers to construct a 1mm graphene later (Woodford 2017). Due to its structure, it presents a number of valuable properties, such as increased strength, thinness/lightness, heat conductivity, electrical conductivity, optical properties and impermeability, all of which make it a highly attractive material for use in a large number of fields (Woodford 2017). For example, graphene is being used in bioengineering due to its ability to penetrate cell walls, or to create ultra-fine anti-biotic water filters for the quick filtration of dangerous drinking water (Templeton 2015).

Yet despite the benefits that graphene offers, it does currently posses a flaw; that being its lack of stability due to its reactive nature, which has consequently limited its current application to a number of fields of research (ManchesterUni n.d.). Researchers have worked to resolve this issue of instability as a material, consequently developing CNTS; which are sheets of graphene that have been rolled up into a nano-scale tube, making it less reactive and more stable (Templeton 2015). Consequently, CNTS are already being applied to a range of different structures to further enhance their existing properties by generating networks within composite materials to increase their strength and weight bearing ability (Boothroyd 2013). Examples of which include items such body armour, vehicles, rockets and building materials (Boothroyd 2013). These examples only represent a fraction of what is currently being considered in relation to nanotechnology, and as we continue to enter into the future, the number of available nanomaterials is only likely to increase due to our increased understanding of the technology.

The third and final key term refers to nanomanufacturing, which is the process of creating nanomaterials, ready for application to various fields of research. Like the previous two key terms, nanomanufacturing also has a number of definitions, but a widely accepted version comes from Lin Li and colleagues (2011, p.735) who describe it as follows:

> *…the production of structures, materials and components with at least one of the lateral dimensions between 1nm and 100nm including surface and sub-surface patterns, 3D nano structures, nanowires, nanotubes and nanoparticles.*

Nanomanufacturing is therefore the scaled-up, repeatable and cost-effective manufacturing of nanomaterials for use in devices or systems (Crawford 2017). The aim of this process is to generate new materials and devices at the nano level in order to produce innovative products, offering improved levels of performance at a lower cost, with greater sustainability (Crawford 2017). There are two main approaches to nanomanufacturing, 'top-down' and 'bottom-up', which are in line with other forms of engineering. The 'top-down' approach involves taking a block of material and removing the parts you do not want until you reach a device or system of correct size and shape (Nanowerk n.d.). This process often utilises vast amounts of energy and chemicals, generating waste, and can also bring about unpredictable and unique results, making its highly challenging to replicate on mass (Nanowerk n.d.). In contrast, the ‘bottom-up’ approach generates products by building up from an atomic and molecular-scale, which can often be a slow and time-consuming process (NNI n.d.; Crawford 2017). Yet despite this, we are very much in the early stages of our understanding of this type of manufacturing, with regular breakthroughs offering new and increasing abilities to synthesize and produce novel commercial materials at the nanoscale, such as new coatings, nanoengineered polymers and nanomachines [Crawford 2017].

3. A Brief Overview of Nanotechnology's Origins

Despite the ‘nanoera’ being considered a modern concept, examples of nanotechnology can be seen throughout human history, dating back to ancient and medieval times (Filipponi and Sutherland 2010). Many examples of this are evident when considering the work of early artisans, who coincidently often worked at a nano-level when creating new products by using nanocomposites (Daw 2012). There are numerous examples of ancient artifacts which were made using nanocomposites, such as the Roman glasswork known as the Lycurgus cup (5^{th} Century), which when illuminated from the outside appears green, but from the inside appears ruby red (Filipponi and Sutherland 2010; NNI n.d.b). The reason for this is that nanosized particles of silver, gold and copper are embedded in the glass, resulting in light absorption and scattering to form different colors (Filipponi and Sutherland 2010; NNI n.d.b). Another example can be seen when considering the Damascus saber blades, which contains CNTS and cementite nanowires; increasing their strength and sharpness, and consequently their overall cutting ability (NNI n.d.b). However, it is important to note that despite their skill, the craftsman would not have known that they were working at the 'nano' level, and therefore should not be considered as a nanotechnologists; they were simply developing new materials through a process of trial and error (Daw 2012). Yet this does demonstrate that it is our understanding of the technology that has evolved, rather than the presence of the technology itself.

Despite these early examples, the concept of the nanoscale was only coined in 1925, through the work of Richard Zsigmo (1925 Nobel Prize Winning Laureate in Chemistry), who used it to explicitly characterize particle size, and was in fact the first to measure the size of particles such as gold colloids using a microscope (Hulla et al. 2015). However, it was not until a lecture given by Richard Feyman in 1959 entitled *There's Plenty of Room at the Bottom* that the idea of nanotechnology as we understand it today emerged (Devon et al. 2007). Although Feyman never explicitly referred to the term 'nanotechnology' in his lecture, he did suggest that it would eventually become possible to manipulate atoms and molecules, in order to produce 'nano-scale' machines (Devon et al. 2007). This was considered the start of nanotechnology as a field of study, hence why Feynman is often referred to as the 'father of modern nanotechnology'. Hence, this work and the influence of others at the time eventually resulted in the emergence of the term 'nanotechnology' 15 years later in a paper entitled *In the Basic Concept of Nanotechnology* by Norio Taniguchi (Allhoff et al. 2010). Taniguchi (1974) used this to describe nanotechnology as a technology that engineers materials at the nanometer level. This resulted in an influx of new research particularly in the 1980s, led by those such as Kroto, Smalley and Curl (Devon et al. 2007; Hulla et al. 2015). One particular driving force behind this movement was Eric Drexler, who in his work *Engines of Creation: The Coming Era of Nanotechnology* proposed the idea of a nanoscale 'assembler' (Drexler 1987). Aimed at a lay audience, Drexler's work outlined a new form of technology based on molecular 'assemblers', allowing for atoms to be placed in any preferred arrangement according to the laws of nature (Drexler 1987). Therefore, although a lot of Drexler's work did not focus on molecular manufacturing, his focus on the scale of the research objects became the key factor, inspiring future research into the field (Allhoff et al. 2010).

Our understanding of nanotechnology was further promoted through the emergence of two key inventions. The first of which was the Scanning Tunneling Microscope (STM), allowing scientists to create spatial images of individual atoms for the first time; and the second being the Atomic Force Microscope (AFM), allowing scientists to view, measure and manipulate materials down to fractions of a nanometer in size (NNI n.d.). Both of these scientific devices enabled researchers to study and manipulate individual atoms to a degree never thought possible before, resulting in the discovery of structures such as Buckyballs (Buckminterfullerence) in 1985, and CNTS in 1991 (Allhoff 2010; Hulla et al. 2015).

Entering into the 21st Century, nanotechnology has become a significant field of research, with an ever-increasing number of studies having been conducted into its use across a wide range of fields of study. This has resulted in the subdivision of the research into three key areas: *nanoscale science*, which is the science of deciphering how materials behave at a nanolevel; *nanomaterial development*, which is the development of new materials for various applications; and *modelling*, which involves the computer modelling of interactions, and the properties of nanoscale materials (Allhoff 2010). Due to its growth as a field of study, nanotechnology is now considered a future technology, which has resulted in significant government investment in its research and development. This can clearly be seen in countries such as America, where the announcement of the Nanotechnological Research and Development Act has consequently given rise to the formation of the National Technology Initiative in 2000 (Hulla et al. 2015). This has since been mimicked by countries all over the world, each of which are also conducting extensive research into this technology in order to exploit its potential benefits.

4. Current Applications of Nanotechnology

Nanotechnology has a wide range of applications, particularly evident in medicine, where nano scale materials along with nano-enabled techniques are being utilised to diagnose, monitor and treat disease (EC 2013). The appeal of nanotechnology's application to medicine relates to its advantageous properties, making it possible to create materials for drug delivery systems that have dimensions on the scale of biomolecules required to regulate the functions of cells (EC 2013). For example, researchers are currently considering a number of different nanotechnological drug delivery systems to treat cancer, where nanoparticles can be used directly to combat cancer cells, eradicating the need for dangerous and risky chemotherapy treatments (NNI 2018). In addition, researchers are also close to developing smart patches fitted with micro needles to deliver insulin for diabetes sufferers, promoting a less intrusive method of treatment (BBC 2018). This patch would also allow for the monitoring of insulin levels, ensuring the right dose is delivered, and improving levels of health care overall (BBC 2018). Nanotechnology is also being trialed for regenerative medical techniques, where scientists are looking to use graphene in order to repair spinal cord injuries, with preliminary research already demonstrating that neurons grow well on conductive graphene surfaces (EC 2013).

Nanotechnology's application to computing and electronics industries is also evident; having already led to the development of smaller and faster electronic systems that are able to store large amounts of data (NNI 2018). It is clear that nanotechnology is already impacting the commercial display market, where for example, nano cells are being integrated into their designs in order to produce more vibrant colours in TVs, whilst also increasing energy efficiency (Nanowerk 2018; Fingas 2017). Moreover in computing, where technology has been used to reduce the size of transistors (the switch that enables all modern computing which used to be around 130-250 nanometers in size), with IBM creating a seven nanometer transistor in 2015, and then Lawrence Berkeley National Lab creating a 1 nanometer version in 2016 (NNI 2018). This has already aided the reduction in computer size, and if this continues, could eventually result in the entirety of a computer's memory being stored on a single tiny chip; propelling computing to the next level (NNI 2018).

The environmental sector has also integrated Nanotechnology; utilising its small size, yet high surface-to-volume ratio, which makes it is an ideal technology for the construction of pollution-monitoring devices (nano-sensors) (EC 2013). Monitoring devices or sensors such as this are able to detect and identify chemical or biological agents both in the air and soil, with considerably greater levels of sensitivity; promoting an early detection system of potential environmental risk (EC 2013). It is evident that the technology is also being used for the purification of water, as engineers have developed a film membrane with nanopores allowing for energy-efficient distillation; able to purify water much more efficiently than conventional filters, which essential for many third world countries (NNI 2018).

Nanotechnology therefore offers a number of benefits to a wide range of fields of research and industry, which has resulted in it becoming a highly sought after technology, and one which is only likely to become more prevalent as we enter into the future as our understanding of it continues to improve.

5. Nanotechnology and Elite Sport

Much like the areas of research outlined above, sports engineers have also identified the potential of nanotechnology, particularly in relation to improving enabling and embedded equipment - promoting improved levels of performance, safety and sporting analysis (Verma 2013). Consequently, nanomaterials such as CNTS, Silica Nanoparticles (SNPs from now on), nanoclays and fullerenes are already being implemented into sporting equipment, with each offering added advantages to sports equipment such as reduced weight, increased strength, abrasion resistance and improved data transfer speeds (Verma 2013; Smith 2018).

There are a number of sports already utilising nanotechnology, such as Tennis, whereby manufacturing companies have started to integrate CNTS into tennis rackets in order to promote additional strength and weight reduction properties, as seen with the Wilson nCode Tennis racket (NNIN 2006; Smith 2018). The application of nanotechnology as part of its design and build has consequently worked to increase the stability of the racket, whilst also increasing its power ratio by 22%; allowing for greater control over the ball and power whilst serving (Taylor 2008). Tennis balls have had a similar application, whereby many are now lined with a nanoclay barrier to preserve ball pressure promoting longer game play (Verma 2003). This has also allowed for increased bounce time in comparison to other more traditional balls; which in turn can promote longer rallies between players (Taylor 2008; Harifi and Montazer 2015).

Golf has similarly exploited the benefits of nanotechnology via the application of nanomaterials such as CNTS to correct imperfections in golf clubs; whereby the construction of the shafts are altered in order to increase the density of the club, making it stronger and straighter (Nano 2017; nanocyl 2007). This has in turn worked to enhance the structural integrity of a golf club, improving power ratios, and allowing golfers to generate greater distances when taking each shot (Nano 2017).

The motor sport industry has enhanced, as well as developed new motor parts as part of its application of nanotechnology; the aim being to improve the performance of a given car via an increase of speed, power and control. For example, in Formula 1, nanocomposites are being used in the body work of each of the cars, helping to reduce weight, and allowing for greater speeds to be reached over shorter distances (Smith 2018). Furthermore, nanomaterials are also implemented to increase abrasion resilience, where small nanoparticles are used to fill the gaps between the paint and metal molecules, working to increase speeds by 37 mph due to improved aerodynamics (Smith 2018). Engineers have also applied nanofibres to the breaking system, which has worked to improve stopping times; essential in not only improving the safety of the sport, but also in supporting a driver by allowing greater control of the car - particularly important when having to navigate a complex track at high speeds (Smith 2018; Butcher 2013; Xiang et al. 2018).

The textile industry within sport has also benefitted significantly from the emergence of nanotechnology; evident through its application in swimming, whereby nanomaterials are embedded within the fabric construction of swimwear, making it ultra-lightweight, and increasingly more water repellent. In doing so, the new product absorbs only 2% of fabric weight, instead of 50% in previous generations of materials used (NB 2018). Properties such as this are highly advantageous to a swimmer, working to reduce weight and drag, and thus allowing for improved levels of performance, as the individual is able to glide through the water more efficiently. It is evident that garments for running have also benefited greatly through the application of nanotechnology, whereby the ultra-fine, high strength polyester nanofibre 'Nanofront' is increasingly replacing insoles in running shoes; promoting excellent frictional properties and moisture absorbance, as well as allowing for greater running comfort (Harifi and Montazer 2015). Many sporting kits are also now laced with fibres that are coated with silver nanoparticles, which meshes with cotton, nylon or plastic fibres. This works to promote the natural antiseptic properties of silver to prevent fungi and bacterial growth, keeping kits cleaner and odour resistant (Smith 2018).

Moreover, the impact of nanotechnology's application may be seen via the construction of sporting facilities; where for example Nano-films are being applied to arena floorings and structures in order to increase their resistance to water and moisture; reducing the potential for rust and defects, and thus increasing their overall life expectancy (Harifi and Montazer 2015). Stadium walls are regularly painted with nano-paints, which include Si02 nanoparticles, which have anti-bacterial, self-clean and anti-stain properties; increasing the purification of the indoor environment, whilst also protecting against ultra-violet radiation (Kai 2013). Whilst nanotechnology's application to floor coverings improves not only an athlete's performance and safety levels, but also increases its durability and cleanliness (Su 2014). For example, gym floors and running tracks have been reported to vastly increase water and oil proofing, along with improving rebound resilience and compressible recovery (Bao-feng 2013).

It is therefore evident that Nanotechnology is already impacting many aspects of sports engineering, including venues, equipment, floor coverings and clothing (Harifi and Montazer 2015). This has had not only a positive impact on sporting systems as a whole, but also the individual athlete; as the technology has generated a number of benefits that have advanced upon the properties of older/existing forms of sports equipment and clothing used by athletes, some of which are summarised below:

- *Enhanced athletes' performance*
- *Enhanced athletes' safety*
- *Enhanced athletes' comfort*
- *Light weight and higher strength*
- *Flexibility*
- *Multifunctional properties such as waterproof, antibacterial, anti-odour, anti-stain, UV protection, heat and cold protection, etc.*
- *Breathability* (Harifi and Montazer 2015, p.1159).

6. A Knowledge Gap - The Ethical Impact of Nanotechnology on Elite Sport

Despite the growing body of new and emerging research literature relating to nanotechnology's application to sporting equipment, there currently exists a knowledge gap relating to its potential ethical impact on elite sport. As a result, nanotechnological-sporting equipment is being deployed into elite sport without proper ethical consideration in relation to how it may affect elite sport, and more importantly, as to whether such an impact would be beneficial or not. This could therefore prove to be problematic, as nanotechnology offers sports engineers a number of significant benefits, which could work to unsettle the already precarious balance between the role of man and machine in and out of sporting competition. Therefore it is essential that this knowledge gap is addressed, offering a greater balance in relation to the technological and ethical development of this technology. Furthermore, addressing this knowledge gap would allow sporting bodies to better determine how best to progress with this technology as we look ahead.

7. Conclusion

The origins of nanotechnology are ancient, with natural forms existing for millennia (Filipponi and Sutherland 2010). However, in recent years, human research and development has led to the formal emergence of the field of nanotechnology (Hulla et al. 2015). This in turn has given rise to specific research into this technology, which has seen the emergence of purposefully designed and engineered nanomaterials, offering advanced properties that are able to benefit a range of fields of study and industries (EC 2013). An example of this has been evident in elite sport, where sports engineers have already identified the potential that nanomaterials such as CNTS can offer, and are already integrating this technology into different forms of enabling and embedded technologies in order to exploit its potential performance and safety benefits (Verma 2013).

Yet despite this, research and development relating to the engineering and production of nanotechnology is still in its early stages, and this is particularly relevant in relation to its application to elite sport. However as our knowledge and understanding of this technology continues to progress, the role it plays within sport is only likely to increase, and so before this technology becomes a staple element of elite sport, it is essential to consider the potential ethical impact it may have. The remainder of this research will aim to address the issue by initially presenting a methodology in order to consider how nanotechnology may be ethically analysed in order to determine its potential impact within the field.

Chapter 4 - Methodology

1. Introduction

To begin, it is essential to note that this work offers considerable originality in relation to its content, due to the lack of research that exists within current academic literature (both sporting and philosophical/ethical) relating to how nanotechnology may ethically impact elite sport. This consequently generates a problematic knowledge gap as referred to earlier; and increased clarity is required not only with regards to nanotechnology's evolving application to sports engineering, but also the potential ethical impact it may have at present, and in future.

Before an ethical analysis can be conducted, a research methodology must first be established. This chapter aims to achieve this, firstly by presenting three nanotechnological case studies, whilst also outlining an effective ethical framework that will be used in order to analyse each coherently. An approach such as this will apply both qualitative and secondary data in order for normative evidence to be established in terms of the potential benefits/disbenefits that this technology may present elite sport[3]. This evidence will later be debated in order to determine how we best progress with its continued application to sporting equipment; hence establishing a key ethical and philosophical foundation for the research, whilst providing a clear analytical structure.

2. The Case Studies

In order to determine the ethical impact nanotechnology may have on elite sport, it is first essential to establish a set of case studies in order to provide normative evidence in which to consider and ethically analyse. To achieve this, a case study approach

[3] The application of qualitative and secondary data will be prevalent throughout this body of work, as it will not be considering primary numerical data, but instead focus on existing publications in order to provide key evidence and arguments. Consequently, removing the need to apply any quantitative research methods.

will be adopted, as this is common practice within academic literature found in both the fields of engineering and sports ethics.

A case study or 'cases' as often referred to within engineering literature refers to narrative that presents real-life scenarios/problems, allowing stakeholders to experience how professionals address problems encountered in a given field; in this instance elite sports engineering (Davis and Yadav 2014). In accordance with Merseth (1994, cited in Davis and Yadav et al. 2014, para.1), a case study contains the following key elements:

> *(1) they are based on real-life events or realistic situations that allow students to experience problems they are likely to encounter first-hand; (2) they present both contextual and technical information that is based on careful research and study; (3) they may present no clear-cut solutions to allow students to develop multiple perspectives.*

The role of a case study is to offer key scenarios that mimic the real world, allowing for problems to be solved and theoretical/conceptual frameworks generated in order to resolve real life issues (Davis and Yadav 2014). This approach offers a multifaceted experience, increasing knowledge of a given area of study, as well as enabling the development of effective solutions to problems in a safe and ethical environment before potential application in everyday life (Fuchs 1974 and Davis et al. 2014). The implementation of a case study approach allows for the technology to be trialed in real life sporting scenarios for greater context to be established, promoting improved knowledge and understanding. This will also offer greater clarity regarding the potential benefits and disbenefits of this technology's use within sport; increasing the accuracy and relevance of ethical decisions made in relation to how best to progress (or potentially not to progress) with its application.

For this research, three case studies have been selected, each of which represent a key category of sports engineering, along with an additional third party sporting application. The first of the case studies focuses on an enabling technology; that being the 'road bike' used in elite cycling. There are two key reasons behind this case study selection; the first being that cycling’s very existence is dependent on the bike as an essential piece of equipment in not only assisting an athlete to success, but also a technological product for the sport. Consequently, any changes made in relation to its design and construction often has a clear and direct impact on a cyclist's level of performance and safety, as seen in previous years with the introduction of new material technologies such as carbon fibre (Hakke 2009). This case study offers an insight into how nanotechnology may directly impact an essential piece of sporting equipment. Despite this, it could be argued that cycling is no different to any other sport that uses an enabling technology, so why select this piece of sporting equipment over any other? This question brings us to the second justification for its selection; as a sport cycling regularly embraces new and advanced forms of technologies, in particular material technologies, in order to improve a bike's design and construction (Fiedler 2017). Consequently, engineers within the sport have already embraced its application, producing equipment such as bikes containing nanomaterials, in the hope of improving a cyclist's performance and safety levels. This presents a valuable and timely opportunity (one not yet available in many other sports due to the infancy of this technology) to determine the existing benefits/disbenefits that nanotechnology may present an elite sport such as cycling; alongside the potential future benefits/disbenefits it may present the sport going into the future.

The second case study focuses on an embedded technology, specifically the nanobiosensor for performance analysis purposes. This case study has been selected due to the field of performance analysis being considered a particular growth area within elite sport, with athletes, coaches and teams increasingly turning to it in order to gain an edge over the competition. This has resulted in an increase in the number of athletes using wearable technologies, such as GPS sensors for example, which offer a greater insight into how an athlete is performing within a given training session or competition (Evans et al. 2016). Yet in recent years, the desire to access more comprehensive athletic data for performance analysis has resulted in the integration of the biosensor to aid athletic performance both in and out of competition. This device is now regularly utilised within elite sport to collect an athlete's biological data, in order to provide a more personal and bespoke account of an athlete's levels of performance and health (Moskvitch 2012). However, due to its limitations as a device, particularly in relation to the range, sensitivity, and speed in which it can collect biological data, it would appear that sports engineers are now looking to potentially resolve such issues through the integration of the nanobiosensor[4]. This new and emerging version of the existing biosensor may soon find its place within elite sport, having already demonstrated early signs of improvement through increased levels of sensitivity, a greater ability to collect a broader range of data, and faster data retrieval for quicker performance analysis (Evans et al. 2016).

Analysis of this case study therefore offers valuable insights into not only how nanotechnology may impact performance analysis, but also providing an opportunity to conduct a 'premortem' in relation to the future application of the nanobiosensor to elite sport. To further elaborate on this point, the term 'premortem' is often used within the fields of business, medicine and engineering, referring to the identification of potential benefits and risks of a project during its inception (or in this case technological application to sport) rather than at its end (instead considered a postmortem review) (Klein 2007). This approach often improves the chances of a project's success (again, in this case the application of nanotechnology to elite sport) as it allows for early risks to be identified, and precautionary measures to be put in place from the start in order to reduce to the chance of a project's failure or the generation of risk to potential stakeholders (Klein 2007). Moreover, it would be advantageous in relation to this work, as it would promote good regulatory practice, allowing for potential benefits and disbenefits of a new and emerging technology before it becomes prevalent within a given sport. Much in the same manner as the first case study, it will also offer an additional opportunity to explore new grounds in relation to the ethical impact of a new and emerging technology, an area that often lags behind that of a technology's progression.

The third and final case study will consider the potential extended use of the nanobiosensor for sports betting purposes, with particular reference to horserace betting. This case study has been selected due to its ability to offer insight into how such a technology such as a nanobiosensor, although developed for performance analysis purposes, could be used for a third party application such as betting, as has been the case with previous sensor technologies such as GPS trackers (TPD n.d.).

[4] Nanobiosensors are defined as a biosensor consisting of nanomaterials and with the dimensions on the nanometer (1 nm = 10-9 m) (Nada et al. 2011).

Much like case study two, this will offer an early insight into the potential impact that the technology may have on the field of betting, as well as demonstrating nanotechnology's versatility as a potential technology form within sports engineering. Moreover, horse racing's recent attempts to evolve its betting practices with the aim of reviving its declining betting revenue streams, particularly in the UK, makes this selection particularly relevant and essential for consideration (Thomas 2014). It is evident that the sport has turned to technological advancement in order to rectify this situation, with the aim of bringing gamblers back to sport (Attkinson 2014). It has however yet to include biosensors, or the more advanced nanobiosensors in order to collect biological data for betting purposes. This is because at present such sensor technologies are only being used within the sport as vetenary aids in order to monitor the health and well being of a horse. Nevertheless, the increased sophistication of the sensor technology in question alongside the potential integration of nanobiosensors may be used to collect additional data in which to bet with, and therefore increase the available betting options for gamblers. Although this is a hypothetical application, it is a foreseeable innovation within sports betting, and is likely to be applied to betting practices in the near future; much in the same way as previous data collection technologies of the past, such as the aforementioned GPS sensor (TPD 2013). Thus, the application of nanobiosensors is likely to demonstrate a similar trend, mainly used for performance analysis purposes and equine health maintenance, but additionally offering potential betting data also. The analysis of this case study specifically would therefore offer original research in relation to nanotechnology's use within sport, offering a wider understanding of the potential benefits and disbenefits that this technology may present the field beyond its direct sporting applications.

The case studies outlined above consider a wide range of nanotechnological applications to elite sport, with the main purpose of offering a 'pre and post-mortem' ethical analysis of each of the nanotecnological applications. The results will then provide essential normative evidence and ethical discussion in order to address the existing knowledge gap that surrounds nanotechnology's ethical impact on elite sport.

3. The Limitations of the Case Studies

In order to promote good research practice, it is essential to address the potential limitations of the above case studies; as with any research, a number of limitations may be identified. The first relates to the minimal number of nanotechnological case studies that are analysed throughout this work. It may be argued that the ethical analysis of three case studies proves much more difficult to establish an overall picture of the potential benefits/disbenefits that nanotechnology may present elite sport. Moreover, alternative case studies may generate differing results to those outlined in this work.

Although this is a concern, it is not sufficient to undermine this research, as the main purpose is not to offer a fully comprehensive account of all potential nanotechnological applications to elite sport. This does not resemble the objective of this thesis, which is to open the ethical discussions (that currently are lacking) in relation to nanotechnology's ethical impact on elite sport, in order to build the foundations for its continued use. Further, as a body of work it does not claim to offer a fully comprehensive account of nanotechnology's potential application and impact on elite sport, but rather to start addressing the existing knowledge gap that currently surrounds our understanding of this field. This research therefore offers an important and relevant model for the analysis of any future nanotechnological case examples that may emerge within elite sport. Again, working to ensure that the integrity and spirit of sport remains protected, and its ethics develops at the same rate as its technological development, rather than it lagging behind. It will also establish a framework in which future nantechnological case studies may be analysed against in order to further expand our knowledge of this technology and its impact on elite sport.

The hypothetical nature of the case studies presents a further limitation, particularly in relation to case studies two and three due to the fact that nanobiosensors have yet to be integrated into elite sport, meaning that the true impact of this technology has yet to be established. Thus, predicting outcomes whilst technology such as the nanobiosensor is still within its research and development stages could result in misleading or even incorrect impact outcomes, encouraging actions to be taken that may not be appropriate. It could therefore be argued that the only real way in which we can fully understand the potential impact of technologies such as this would be to integrate it within a given sport initially, enabling the benefits/disbenefits to come to the fore, to then conduct an ethical analysis based on its real life outcomes.

Although a valid point, one could argue that 'pre-mortem' discussions such as this are an essential process in promoting ongoing safe and ethical research. This research is no different, as identifying the potential benefits and disbenefits of a new technology's use in elite sport such as nanobiosensors should not be viewed as restricting the emergence of a new technology, but rather promoting good research practices. Further, the benefits and disbenefits identified in this work in relation to nanobiosensors will be evidence-based, inferred from existing knowledge available in relation to the very similar biosensor, already implemented within modern elite sport. An approach such as this should therefore not been seen as problematic, but rather a method of good governance practice, and an action plan which is commonplace within the majority of industry that have to deal with the integration of new and emerging technologies. Once integrated, future research will allow for comparisons to be drawn, and the validity/accuracy of the prior ethical analysis to be conducted in order to improve practices thereafter.

The final limitation relates to the broad nature of the case studies selected for ethical analysis within this research; which may be perceived as offering a shallow analysis of nanotechnology's possible impact on elite sport, only touching the surface of each of the key areas of sports engineering. An alternative approach may offer a narrower focus, increasing the depth of knowledge in relation to a single area of sports engineering, such as enabling technology for example. Yet, this limitation fails to recognise the primary aim of this research, which is to open the discussions surrounding nanotechnology's ethical impact on elite sport through consideration of its application to the field. Therefore to achieve this, it is essential to address a wide variety of case studies across the field of sports engineering, so that an overall picture may be established. Consequently working to further our knowledge, and challenge the existing problematic knowledge gap that exists in relation to nanotechnology's use in sporting equipment at the elite level. This would help to aid future research, which could in turn offer a more comprehensive study of each of the key areas of sports engineering.

4. Determining an Ethical Analysis Framework

Before conducting an ethical analysis of the case studies, it is first essential to establish a clear ethical analysis framework. The assessment of the possibilities and weaknesses of ethical frameworks such as this will allow for the systematic analysis of the case studies at hand, further improving focus of this research (Loland 2002). Before discussing the specific ethical approach that may be selected in order to conduct this analysis, it is first essential to clarify what is meant by 'ethics'.

The term itself originates from the Greek word *ethos*, referring to 'habit' or 'custom', and in its simplest form could be considered as a system of moral principles, that inform people how to make decisions and conduct themselves in their everyday lives (Loland 2002). In modern philosophy, ethics is generally divided into three distinct categories; the first of which is 'meta-ethics', exploring the connection between values, reasons for actions, and human motivation, addressing how its moral standards might provide us with reasons to act or not act in a given situation (Sayre-McCord 2014). Meta-ethics therefore deals with the nature of moral judgment by looking at the origins and meaning of ethical principles. The second is known as 'normative ethics', which is the study of ethical action, and is concerned with the content of moral judgments, as well as determining intrinsic value to identify whether actions are right or wrong (Gray 2014; Kagan 1992). Normative ethics is therefore concerned with more practical tasks in relation to meta-ethics, alongside how we ought to act and defend the basic principles of morality[5] (Gray 2014; Kagan 1992). The third and final division of ethics is known as 'applied ethics', considering key topics such as the Just War theory, animal rights and environmental concerns; applying decision-making tools to real life scenarios, in order to reach informed and justifiable choices (Singer 1986; Attfield 2006). This approach is devoted to the treatment of moral problems and practices not only in an individual's personal life, but also relating to professions, technology and the government. It is therefore in contrast to more traditional ethical theories (which are purely concerned with theoretical problems) as it takes its point of departure from practical normative challenges (Petersen and Ryberg 2016).

[5] Kagan (1992) would argue that such an account of normative ethics is valid but does not go far enough. It lacks is a sense of the major regions of normative ethics and how they relate, something she addresses in her work as referenced (Kagan 1992).

With the consideration of sports engineering (along with the field of engineering as a whole), an applied ethical approach has traditionally been adopted in order to address and discuss key issues, underpinned by normative frameworks in order to establish evidence for ethical debate (Brey, P and Jansen, P 2015; Singer 1986; Attfield 2006). This process involves the analysis of a specific and controversial moral issue relating to engineering's application to elite sport, such as the emergence of a nanotechnology. Here, normative research is used to generate significant debate as witnessed in chapter two. However, this has resulted in the emergence of two polarised schools of thought, where some consider sports engineering as essential for the continued evolution and increased safety of sport; whilst others state that its growing application and use is detrimental to elite sport, working to devalue competition and blur the lines between the role of the athlete and that of the technology. This debate therefore characterises an applied ethical approach with differing viewpoints of the rightness/wrongness of new and emerging technologies use at the elite level; as if everyone was in agreement, it would no longer be considered as an applied ethical issue. Consequently, in coherence with technologies that have gone before it, it may be established that the most suitable ethical approach in order to ascertain the impact of nanotechnology to elite sport would be via the applied approach.

At present, adopting an applied approach such as this may be problematic for two reasons; firstly, due to the lack of normative evidence (and argument) available in relation to nanotechnology's potential ethical impact on elite sport, creating the aforementioned knowledge gap; secondly due to the lack of consensuses on an agreed ethical theory in relation to this technology. Consequently, in order to determine the potential impact of this technology's use within elite sport, it is essential to deduce normative evidence through analysis of the case studies discussed above, which will then inform an applied ethical framework. In order to conduct such an analysis, a normative decision framework must also be established in order to determine the benefits/disbenefits of each of the case studies. Further, selecting this framework in order to achieve outcomes is challenging, as it should not be too narrowly focused, and must offer value for those on both sides of the sports engineering divide. Thus, the selection of a suitable framework is therefore essential to this ethical analysis; and in order to determine which normative approach would be most suitable, it is essential for us to generate a foundation of knowledge to best dictate which framework to deploy when analysing the case studies.

Normative ethics has a dual nature, and can be considered as deontological or teleological. The former focuses on moral duties, arguing that these form the foundations of moral rules, and for an action to have moral worth, it must conform to a series of pre-defined rules or duties[6] (Larry and Moore 2016; Vallentyne 1987). There is intrinsic value to be gained when conforming to pre-defined rules and duties such as this, as for example, by following a rule such as 'do not murder', implies that you as an individual also have the right not to be murdered (Larry and Moore 2016). There are many examples of a deontological approach to ethics, including the Divine Command Theory and Kant's moral theory (Vallentyne 1987). Both approaches offer a number of benefits, mainly in relation to its simplicity and universality. Since it is a rule-based ethic, what is deemed as a morally correct course of action is the one that conforms best to a set of presubscribed rules (Larry and Moore 2016). In contrast, actions that are seen as morally incomprehensible are those that do not conform to such rules. For example in a sporting context, if a new technology were to be applied to a given sport, and done so within the confines of the rules, then its application would be viewed as morally permissible. However in contrast, if this technology were to be applied to another sport, and this was in breach of the rules, then the technology would be rejected and viewed as an underhand method of gaining an unfair advantage over others. Hence, a deontological approach is straightforward, universal, and does not concern itself with the consequences of a given decision, making moral choices more clear-cut[7].

Nevertheless, despite such benefits, a deontological approach is arguably not best suited as an ethical framework principle for the analysis of each of the case studies in this research. There are a number of reasons for this; first, at present there are no

[6] A point should be made here that some argue that the characterisation of deontological ethics as a rule-based theory is problematic, as both deontological and teleological theories may be (and generally are) rule based (Vallentyne 1987). The difference between the two can lie instead in the kinds of rules they invoke, leading to some such as Rawls (1971) characterising it as simply as theories that are not teleological.

[7] It could be argued that this consideration of deontology is tied too closely to sporting rules rather than broader rules and principles. Although a valid point, it would seem sensible to link it more closely with sporting rules, due to the nature and purpose of this work, in order to determine its suitability as an ethical approach in order to review the case studies.

specific rules available to govern the nanotechnological examples outlined above. Thus, this technology is at present not in breach of any existing regulation, as there is none; therefore in accordance to a deontological approach its use could be morally justified. Yet it may be argued that reasoning such as this in relation to the case studies is flawed due to the infancy of this technology, this is due to the fact that sport specific rules are not presently available to govern the use of nanotechnology in the elite field. However, a key point to make here is that this does not imply that they will not be in the future, especially if 'nano' specific rules for sport are devised and implemented. Secondly, there is a lack of knowledge relating to the potential of this technology, and without such information, it is challenging to identify and discuss how nanotechnology may impact the nature and values of elite sport. This consequently needs to be established first, allowing for more deontological-based frameworks to be effectively applied.

Due to a lack of current specific sporting ruling for nanotechnology, and assuming that there are no intrinsic reasons for condemning the application of this technology's use within elite sport, it would be fair to assume that the moral status of this technological application can only be determined by an evaluation/analysis of its expected outcomes (Häyry 1994). It would be logical therefore to adopt a teleological or consequentialist approach as an ethical analysis framework to ethically discuss the case studies. An approach that focuses on the consequences of a given action, which with regards to the case studies is essential to determine, particularly in light of the current lack of regulation. Consequently, values in accordance to a teleological ethic are justified in accordance to a final purpose or an end good (Korsgaard 1998). Thus, the rightness or wrongness of an action is based on its consequences, with examples including Ethical Egoism and Utilitarianism (Regis 2019; Vallentyne 1987). Teleology is therefore simple in nature, and easy to apply, making it a versatile principle, but its use in relation to this research is better suited, and will be applied in order to ethically analyse each of the case studies discussed in this work.

The justification for this choice lies within the current absence of rules and knowledge in relation to nanotechnology's application to elite sport, and the intrinsic need therefore to consider the potential consequences this technology may generate for a given sport. Adopting this approach allows for the establishment of normative evidence in the form of a series of benefits and disbenefits relating to each of the case studies. This data may then be used to inform an applied ethical discussion when determining how best to progress with this technology's use within sport in the future, understood within. The role of consequentialism therefore is to act as the principle normative framework for the evaluation of the benefits and disbenefits to the technology, and the understanding of which will contribute to an overall eclectic ethical approach. As a result, this work does not claim to conduct any type of fundamental philosophical scrutiny of the underlying ethical theory, as befits a less applied study. Instead it aims to use consequentialism as a means in which to frame the applied ethical issue relating to nanotechnology's application to elite sport, but it also assesses the significance of this empirical data in association with other ethical concerns proper to – and not exhausted by, consequences of nanotechnological applications in sport (such as privacy rights, duties not to harm athletes by unsafe products, and so on).

It should be noted that eclectic ethical approaches are hardly atypical in applied ethics studies, so the present methodological choice is not exceptional. Serious appreciation of consequentialist considerations are regularly adopted and privileged in other fields such as engineering ethics and bioethics in order to address similar issues. Consequently, enabling normative evidence to be established when knowledge and governance is limited relating to an action or technology, for example enabling ethical debate, and therefore more informed decision outcomes to be made (Davis and Yadav 2014; Beauchamp and Childress 1979). Further, and highly relevant to technology based ethical evaluations, consequentialist approaches typically embrace the Harm Principle, which functions to reduce third party risks associated with innovations (Mill 1859). But sports ethics reaches beyond consequences, indeed it is rarely employed as a monolithic ethical approach there. These points are elaborated upon further in Section 8 below.

In order to effectively establish a wide range of possible benefits and disbenefits, a generalised consequentialist framework will be adopted. This will allow for greater certainty to be ascertained in the first instance in relation to the potential ethical outcomes this technology may generate both in terms of its benefits and disbenefits

(Häyry 1994). Further, by taking such an approach, it allows for a broader number of potential benefits and disbenefits to be established, informing greater levels of debate that specific versions of consequentialism would potentially limit, due to having narrower focuses. Following review of the case studies using the generalised consequentialist framework, additional variants of consequentialism may also be applied to further enhance knowledge and improve certainty of outcomes.

5. Consequentialism - Definitions and Origins

Before considering the potential strengths and weaknesses of adopting a consequentialist approach, it is first essential to establish a knowledge foundation in relation to teleological ethics. There is much debate surrounding the origins of this ethical approach, yet despite this, it is generally perceived as having given notoriety with the emergence of classical Utilitarianism, formulated initially by Bentham and later progressed by Mill (Sinnott-Armstrong 2015). This approach to ethical decision-making promotes the ideals of hedonistic act consequentialism, arguing that an action is only right if it maximises the greatest good/happiness for the greatest number (Bentham 1789; Den Uyl 1983; Mill 1859). Further, the use of the term 'good' was done so in terms of generating the greatest amount of pleasure viewed as intrinsically valuable, thereby making it a hedonistic value system (Bentham 1789; Den Uyl 1983; Mill 1859; Driver 2014). This philosophical approach is distinguished by its emphasis on the key idea that all happiness should be considered equally rather than individually, in order to promote the greatest amount of happiness. Consequently, when one looks to maximise the good they produce, they should do so where the resulting outcomes are considered equal and beneficial for all, and no one's 'good' is better than any others (Driver 2014). Moreover, a consequentialist agent is not permitted to prefer themselves, nor their loved ones when choosing a distribution of benefits and burdens, implying a very direct and rigorous version of impartiality[8]

[8] The strict nature of consequentialist impartiality can be very demanding and is, for the consequentialist, a catch twenty-two position. Based upon the popular view that a moral theory must be deeply impartial, consequentialists will often meet this (Troy 2018). Further, consequentialists have typically been skilled at exploiting this fact with often-strong rhetoric (Troy 2018). Conversely, the strict impartial demands of this theory are for some so strict critics have stated they are unacceptable, and therefore should be rejected as unrealistic (Scheffler 1982; Slote 1985; Williams 1981).

(Troy 2018; Williams 1981). Such attributes to this ethical theory are valuable to this research, as it allows for the merits of different actions to be morally assessed in a neutral manner, which is vital to the process of ethically analysing the case studies.

Therefore, although classical utilitarianism reduces all morally relevant factors to their given consequences, which may appear simplistic on the surface, it actually consists of a complex combination of many distinct claims including evaluative consequentialism; hedonism; maximising consequentialism; aggregative consequentialism; total consequentialism; universal consequentialism; equal consideration and agent neutrality as discussed earlier (Sinnott-Armstrong 2015). Such claims can be subdivided further, but what is important is that most pairs of these claims are logically independent, so a moral theorist could accept some of them without accepting others. Yet classical utilitarian's accept them all, thereby making it a more robust and complex theory than it would first appear (Sinnott-Armstrong 2015).

6. Variations of Consequentialism

Since its formal conception within classical utilitarianism and the coining of the term consequentialism in 1958, the theory has flourished, and there are now wide variations of this theory, all of which differ in terms of the types of consequence they accept in a given moral situation (Anscombe 1958). For example, State Consequentialism (an ethic which is rooted in ancient China, which some argue is actually an example of the first form of a rough version of consequentialism) emphasises the search for an objective moral standard or model, that can guide the actions of the state, society and individual in a reliable manner; with the aim of producing beneficial and morally right consequences (Harris 2016; Frazer 2015). In order to improve the chances of promoting such beneficial outcomes, state consequentialism opposes actions that may result in the escalation of military aggression and waste for example, as neither are beneficial to the greatest number (Frazer 2015). Those who follow this form of teleological ethic are primarily concerned with social reform, and then individual morality, with the goal that everyone conforms to moral righteousness (Harris 2016). Further, those who adhere to this ethic also tend to assume that all individuals are motivated to do what they think is right, and with a proper education will be able to do this; promoting moral consequences to their actions (Frazer 2015).

An alternative version of consequentialism is ethical egoism. This moral doctrine states that the consequence of any decision should aim to promote the interest of the individual over everything else (SPI 2017). Ethical egoism is therefore concerned less with societal consequences, but rather the individual in a given moral situation. Fundamentally ethical egoism views the consequences of person's actions as more important than any other possible resulting outcomes from a moral situation. This ethical stance has drawn a number of critics, who argue that despite its benefits, it is still a fundamentally egoistic and self-centered ethical doctrine, failing to take into account the needs of others within society, or even used to justify their potential exploitation (SPI 2017). Although such a criticism is relevant, it is not necessarily true, as by taking advantage of another does present risk as there is a chance they could be found out, which would not be in the interest of the egoist, as this would generate worry that is an adverse consequence (Thomas 1980). Further, as Rand (1964) states, despite this being a self focused ethic, it does aim to show all people equal respect, and avoid arbitrarily doing harm to others, even if efforts to do so are arguably not the main focus of an egoist efforts, and such actions are taken to still promote their own interests (Rand 1964). Consequently, ethical egoism promotes a value system outlining that individuals should look to better themselves by investing their efforts into their own personal development, without causing unnecessary harm to others within society (Rand 1964; Shaver 2014). Not to be confused with psychological egoism, which is based on the principle that all humans are motivated by self-interest (ego) in all interactions they may undertake (Fields 2017; Shaver 2014). Conversely, for a psychological egoist, the interest of another is not of any value at all, and all that is of importance is behaving in such a way that promotes long-term self-satisfaction and gratification (Fields 2017).

A further variant of consequentialism is that of altruism, a term first coined in the 19^{th} Century by Auguste Comte, and one that is guided by the principle that the consequences of an action should aim to promote the interests of others (Feigin et al. 2014). Comte (1852) stated that all individuals therefore have a moral obligation to renounce self-interest and live for others. Thus, actions and behaviour that are normally described as altruistic are those that are motivated by a desire to benefit someone other than oneself for that person's sake (Kraut 2016). In general terms, an altruistic act is one of selfless concern towards the welfare of another, and is viewed as a form of consequentialism (Kraut 2016). Consequently, altruism does not only promote actions that are undertaken in order to do/promote 'good' for others, but also those carried out to prevent harm (Kraut 2016; Seglow 2004).

This theory draws similarities with other consequentialist theories such as rule-consequentialism and act-consequentialism, which are also prominent forms of this teleological ethic in today's society. The latter presents the claim that people should make decisions in relation to the rules justified by their consequences, and that the conditions under which moral sanctions should be applied are determined again by rules relating to their consequences (Hooker 2016). For someone who follows rule consequentialism, the rightness of an action does not depend on the goodness of the consequences, but rather whether it is in accordance with a certain code or set of established rules (Douglas 2008). However, in order to make the correct decisions, it is first essential that the rules which are adopted are clear, reasonably simple and easy to comply with, making it accessible to as many people as possible (McNaughton and Rawling 1998). In contrast, act consequentialism states that the rightness of an act is less concerned with the rules, but is rather dependent on whether an action maximises the most good, and that such an act is only right when it generates the greatest amount good in relation to bad consequences (Portmore 2008; McNaughton and Piers 1998). As a consequence, this ethical approach can be objectively or impersonally ranked in accordance to its goodness, and that an act is only morally right if its consequences are at least as good as another alternative option available (Slote and Pettit 2008).

Hedonism is another variant of consequentialism, characterised by its openness to pleasurable experience, and that the idea that pleasure making is the main motivator of human behavior (Veenhoven 2003). In accordance to this theory, humans are said to have a desire to do what is best for their own cause (known as 'self love') and define the term 'best' in terms of pleasure and pain (Chandler 1975, p.223). Hedonists generally define pleasure broadly, including pleasant feelings or experiences such as contentment, ecstasy and joy; in contrast, pain or displeasure includes unpleasant experiences and feelings, such as ache, grief and hurting (Moore 2013). Much like the other forms consequentialism, there are a number of different variants in relation to hedonism, such as psychological hedonism. This states that pleasure is the only thing deserving of our aims, and is consequently often described as 'panhedonism', or universal hedonism, as it outlines that all human endeavors are directed towards pleasure (Tatarkiewicz 1950).

The final example of consequentialism that I will outline in this chapter is that of situation ethics. A theory that was founded by Joseph Fletcher, and states that what is right or wrong is dependent upon the given situation, therefore rejecting Legalism and Antinomianism in favour for decisions to be made on a case-by-case basis (Fletcher 1966). Further, in a given moral situation, one should try to take the most loving action, with the aim of maximising harmony and reducing the potential for discord, consequently enriching human existence (Rosenthal 2017; Fletcher 1967). Fletcher based his ethic on the general Christian norm of brotherly love, which is used in different ways depending on the situation; perceiving absolute rules as restrictive and undermining the complexity of a given situation (Fletcher 1967). Yet this does not imply that all rules should be rejected, as some actually promote loving consequences, and when they do they should be followed (Rosenthal 2017). In contrast, if such a rule put people at risk, and fails to promote loving consequences, then it should be re-thought, and in some cases even rejected. Moreover, according to Fletcher, moral judgments are decisions not conclusions, and should seek the wellbeing of people, through actions of love, which is the only intrinsic good (Fletcher 1966/1967). Fletcher’s work is a clear attempt to demonstrate how acts can be considered morally acceptable even if they go against so-called moral laws in order to promote the most loving consequences (Dimmock and Fisher 2017).

The theories of consequentialism are therefore broad in nature, offering considerable variations, each of which have different approaches to human actions/interactions, and place different values on the consequences they produce. Despite this, what unifies each of the theories of consequentialism is the importance they place on the consequences of a given action, rather than the reasons as to why such an action has been conducted in the first instance.

7. The Benefits and Limitations of a Consequentialist Approach

Now that a foundation of knowledge has been established in relation to the differing variants of consequentialism, this next section will consider the potential benefits and limitations of applying this principle as an ethical analysis framework in order to consider the above case studies. It will begin with the benefits, moving on to then consider the limitations, presenting a discussion in relation to each point made.

7.1 The Benefits

The first benefit of this ethical approach is that it aims to produce results that offer greater levels of happiness and consequently work to reduce unhappiness (Bentham 1789; Den Uyl 1983; Mill 1859). This form of decision-making requires an individual to carry out an evaluative decision-making process, ensuring that any choice that is made requires benefits to outweigh the potential risks, which should be avoided. As a result, an action is considered only as rationally justifiable as long as it promotes good overall, and since we ought to do what is rational and justifiable, we should therefore act in such a way that does most good (Haines n.d.). Hence, this approach could be used to justify acts that bring both justice and injustice, as an act which is deemed as an injustice may actually be justifiable if it brings about more good than following the strict demands of justice (Grisez 1978). Subsequently in relation to the application of nanotechnology to elite sport, it would offer a balanced approach to determining the impacts of this technology, due to the fact that it would consider whether nanotechnology would be a benefit to a sport as a whole, and not just for the minority that can cause fairness/equality issues. Thus, taking into account key stakeholders within the decision-making progress, such as athletes, coaches and teams as a whole; as well as ensuring that sport remains a level playing field, reducing the opportunities for injustices that could be generated via the use of this technology. Furthermore, it would take into account whether this technology could also be beneficial in terms of health and financial factors, ensuring that all aspects of nanotechnology's ethical impacts are taken into account in order to determine the best decision outcomes.

Another benefit to a consequentialist approach is that in most cases it would appear sensible to centre decision making around consequences, as it is often the case that the actions that lead up to a final result are forgotten about. Actions are therefore often considered transient in nature, with the outcomes and implications regularly holding significant importance in a given situation (Haines 1995). Choices are often determined on the basis of their outcomes, as shown when public officials proceed with projects, they consider the expected costs and benefit outcomes, weighing them against each other, and offering little focus as to why such an act is being performed (Grisez 1978). A point that is relevant when considering nanotechnology's current and potential application to elite sport. The reasons for application of the technology to sport are accepted, with sports engineers aiming to produce greater performance and safety outcomes for an athlete, which in turn brings about other benefits such as financial and spectator gains for the sporting system as whole. Such reasoning has a long history in elite sport, and is widely accepted, and often encouraged. Yet what is often vital for review is the impact a new technology such as nanotechnology may produce for a given sport, as this is predominately a marker of success or failure. To exemplify this, we may consider the aforementioned Speedo LZR Racer suit; originally integrated into the sport of swimming based on the above reasoning and accepted for use amongst athletes. It was not considered a breach of any ruling, and some even argued it was actually a relevant performance step for the sport (Dorey 2012). The reasons for its application were of little concern, particularly as the manufactures were acting within the rules, however it was not until the consequences of this technology's use were established with numerous records broken, that FINA decided to act, banning it on the grounds of technology doping (Dorey 2012). Thus, the reasons for its application to swimming as a technology were quickly forgotten due to its perceived negative impacts on the nature and integrity of the sport, demonstrating the transient nature of actions. The same applies when considering nanotechnology's application to elite sport, as at present, the reasons for its application are generally understood and accepted, hence why it is already playing a role in new and emerging sporting equipment. But the success or potential failure of this technology is likely[9] to be determined by the consequences it produces.

[9] Other factors may also be considered in relation to whether nanotechnology is deemed a potential success or failure. They may include how it interacts with a given sports values, spirit and internal goods for example.

A final benefit of consequentialism is that it is simple in nature, and therefore easy to understand; based on common sense, and does not require a complex theoretical framework in order to establish what the best potential outcomes of an action would be (McNaughton and Piers 1998; Regis 2019; Vallentyne 1987; Stubbs 1981). This provides potentially universal application, meaning that it can be applied simply and clearly in any given situation. Consequently as a principle it is self-evident, as a consequentialist would hold the view that you have to judge the success of a given choice in relation to its outcomes. This therefore generates a clear structure for making ethical decisions, where people will strive to act morally in order to produce the greatest levels of good and happiness in any given moral decision. This is essential when considering the ethical analysis of nanotechnology's application to elite sport via the case studies outlined above. The clearer the outcomes, the easier it is for a sporting body to take clear and decisive action. Therefore, if nanotechnology in relation to the case studies produces positive results, then its further integration may be supported; in contrast, if the consequences of its application are negative, then action should either be taken to monitor and reduce such risks or prevent them from occurring altogether.

7.2 The Limitations

Despite such benefits, a consequentialist approach does also present a number of limitations. One particular example is that it can be challenging to predict future consequences of a given action; since behavior is considered to be an assessment of consequences, should judgments be made in relation to what we think may happen or what actually does happen? We may believe that we are acting in a way that promotes the greatest good, but it may not be as straightforward as that, as predicting all future outcomes is impossible. This can clearly be seen when considering previously integrated technologies into elite sport, such as those discussed earlier, the LZR Racersuit and Polara golf balls (Dorey 2012; Hardman 2014). Both technologies were introduced in order to further improve the sporting practices of golf and swimming, by enhancing athletic performance levels (Dorey 2012; Hardman 2014). These actions appear logical, as the nature of sport implies such progression; however, each of the cases were actually deemed to limit each of the sports via deskilling, an outcome that was not likely expected or intended (Dorey 2012; Hardman 2014). Further, if we do manage to successfully predict the potential outcomes of a decision, measuring the goodness of these actions does present an additional challenge, due to the fact that everyone has differing opinions on what is considered to be 'good'. Moreover, the consideration of what makes one person happy may not be the same for another (Stubbs 1981; Hardman 2014), which is of particular relevance when considering the ethical analysis of the nanotechnological case studies referred to in this work.

Two of the case studies centre upon discussions revolving around nanobiosensors, a technology that is still in its early research and development stages, and has yet to come to prevalence within the sporting and betting arenas. Therefore, the benefits and disbenfits of this technology presented via a consequentialist analysis could indeed be incorrect. For example, what may be identified as a potential benefit of this technology for one sport could represent a disbenefit to another, and hence, there is may be a real margin of error during this process that must be taken into account. Yet despite this, such benefits/disbenefits will be evidenced based, taken from similarities that can be drawn from existing biosensors (Evans et al. 2016). Moreover, there will be a foundation of knowledge in order to determine such consequences, reducing the potential for error, and increasing academic credibility. Future research should however be carried out in order to increase the width and depth of such a study in order to consider nanotechnology's potential impact in relation to a range of sport.

Consequentialism is built on the idea of impartiality, where one is required to give as much weight to the needs of all stakeholders when making choices (Haines 1995; Everett et al. 2018; Troy 2018). But is this truly possible? Despite how impartial one wishes to be, complete impartiality is almost impossible to achieve, particularly at the demanding levels implied by consequentialism (Scheffler 1982; Slote 1985; Williams 1981) For example, when deciding what to do with your money, a consequentialist would argue that perhaps you should give it to the homeless in desperate need of it, as this could generate greater levels of good. This in reality is not often the case, as when deciding whom you are to spend your money on, you are normally morally permitted to favour yourself than a stranger, creating a clash between consequentialism and common sense[10] (Haines 1995; Jackson 1991; Kidder 2003). Furthermore, it is easy to be biased when using a consequentialist framework, as ethical choices are likely to differ dependent on which group they use to make such moral calculations. A statement argued by Arneson (2005) and de Lazari-Rakek and Singer (2014), who indicate that there is a potential gap between the considerations which are suitable for public acknowledgement, and those which really do determine moral right and wrong. This could also be the case when considering the nanotechnological case studies; for example, the disbenefits in relation to an athlete's health or fairness in performance could be overlooked for the potential financial revenue streams that this technology could generate for a given sport. Further, due to the final decision being made by the regulating body of a given sport, it is always difficult to know how much impartiality there is when decisions are made; are the needs of the athlete given more weight, or the needs of the sport as a whole? If this technology were to make a sport more exciting and engaging for spectators, it could potentially be used to overlook any inequality issues that may be presented, generating an uneven playing field for the competing athletes. Although a valid point, in relation to this thesis, sporting bodies will not be determining the benefits and disbenefits of this technology, and the overall outcomes of the case studies. Such decisions will therefore be carried out as impartially as possible due to lack of any affiliation with any given sport or regulating body. Further choices made in relation to how best to progress with this technology will be made, considering both the individual athlete and the sporting system as a whole with regards to the case studies.

Finally, some argue that a consequentialist approach fails to take into account and respect the integrity of the individual involved (in reference to sport, the athlete within competition or training). Due to a focus on the result being the only thing that matters, how a person acts or how they arrive at that decision is irrelevant, which can be dangerous and result in individual rights being restricted, and their personal business being 'meddled with' (Baker 2016; Frey 1984). This can be exemplified via

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[10] This generates a further ethical issue is relation to giving to the homeless. There are some who will always give, as they hold it to be their duty to promote overall good within society. In contrast, there are those who refuse to give to the homeless, as they reject the idea that it produces beneficial outcomes, as such action could actually be more detrimental to society, resulting in greater drug related issues and violence for example.

the following thought experiment developed by Bernard Williams (Smart 1973, p.96/97) known as 'Jim and the Indians':

> *Jim finds himself in the central square of a small South American town. Tied up against the wall are a row of twenty Indians, most terrified. A heavy man in a khaki shirt turns out to be the captain in charge and explains that the Indians are a random group of the inhabitants who, after recent acts of protest against the government, are about to be killed to remind other possible protestors of the advantages of not protesting. However, since Jim is an honoured visitor from another land, the captain is happy to offer him a guest's privilege of killing one of the Indians himself. If Jim accepts, then the other Indians will be let off. If Jim refuses, then Pedro will kill them all. The men against the wall, and the other villagers, understand the situation, and are begging him to accept. What should he do?*

In this example, a consequentialist would argue that Jim should shoot the Indian, and preserve the lives of the others, promoting the greatest good. However the issue with this is that the consequentialist fails to take into account the impact this choice would have on Jim's life, as Jim goes from being a tourist to a murderer for the sake of morality, which could challenge his own internal belief systems (Baker 2016). This example demonstrates that consequentialism disregards an agent's own personal commitments and supports negative responsibility (being held morally accountable not for some action, but failing to act to prevent bad things from happening), generating impersonal standpoints that can result in unrealistic expectations and potential alienation of an individual (Baker 2016; de Lazari-Rakek and Singer 2014). An issue which could also be relevant when considering nanotechnology's potential application to elite sport; this is because decisions taken based on a consequentialist principle could have a potentially damaging impact on the individual athlete. For example, if it were deemed that the use of nanobiosensors were to be acceptable within a given sport, then an athlete would likely be required to wear such a device. But does this take into account an athlete's own view on this matter? Does an athlete wish wear such a device, and would they have the ability to refuse? The expectation would be for the athlete to wear the sensor and promote the greatest good for their potential team, but this could come at a high cost to their personal life due to the risks surrounding an invasion of privacy. At this point it is worth noting that in relation to case studies one and two; the individual athlete is also taken into consideration, along with equine welfare within case study three. The implications of such are that this ethical framework offers a more comprehensive and personal approach for the analysis of the case studies, where the values and integrity of both the individual athlete and sporting system as a whole are considered with equal respect. This maintains that the technology remains a tool for athletic and sporting use and not vice versa, preventing athletes (or horses) from simply feeling like 'guinea pigs' for technology, or for it to impede their private lives (Evans et al. 2016; MacGregor et al. 2012). In addition, as all of the case studies have an element of predictive decision making, this prevents the argument that it may support negative decision making, as this processes would involve the identification of early risks, promoting action be taken in order to limit such risks.

A consequentialist approach to ethics therefore generates both benefits and limitations in relation to its use as an ethical analysis framework for the case studies. Yet despite such limitations, I still believe that its benefits outweigh its limitations, as referenced above. This is because it bases its judgments on its consequences as a principle, essential for determining the benefits and disbenefits of the nanotechnological applications within the case studies. Moreover, it promotes an impartial beneficence stance, where outcomes are not influenced by personal factors, but rather by what it best for both the sport as whole and the individual athlete, ensuring that the best ethical decision is taken (Everett et al. 2018; Troy 2018), essential for not only protecting the integrity of sport, but also the rights of the athletes themselves.

Further, such a consequentialsit approach is complimentary to the overall applied ethical position this work will take, allowing for formative knowledge (which at present is lacking in terms of nanotechnoloy's ethical impact on elite sport) to be established in terms of benefits and disbenefits, informing moral debate in relation to its use and application within sport.

8. The Need for a Hybrid Approach

As indicated above, although this study employs a predominately consequentialist framework, it does not disregard the importance of other more deontological concepts and approaches that are also relevant to the use of sports engineering and technology, such as those relating to sporting values, rights and justice (James 2010). Consequently, when useful to aiding and encouraging the debate regarding nanotechnology's application to elite sport, such concepts will be drawn upon and discussed.

The study, therefore, can be considered to adopt a 'hybrid' applied ethical framework. It is not 'pure' in form, but instead draws upon the values offered by both ethical approaches, promoting further debate, and generating more evidence in which to determine the role in which nanotechnology may play within elite sport and therefore the level of (if required at all) regulation it requires.

A comparable approach is that of principlism within bioethics, which is centered upon four moral principles established by Beauchamp and Childress in the locus classicus of the field; *Principles of Biomedical Ethics* (1979).

Based on what they describe as four, mid-level principles they combine ethical theoretical approaches. These are summarised as follows:

1. Respect for autonomy - respect for the decision-making capacities of an autonomous person.

2. Non-maleficence - requiring that we do not cause harm to others.

3. Beneficence - requiring we prevent harm to others.

4. Justice- requiring the fair distribution of benefits, risks and costs (Beauchamp and DeGrazia 2004, p.57; Beauchamp and Childress 1979).

These principles form a normative ethical framework designed to support bioethical decision making, with each principle being considered prima-facie binding and universal (NCCFHPP 2016, p.3). Further it states that moral obligations are considered practical or not by being applied to particular contexts (Beauchamp and Rauprich 2016). Therefore, in a given bioethical situation, these principles are used in concert with each other (with no hierarchy system) in order to promote the greatest good for each individual patient coherent with their autonomous wishes (Nardo et al. 2019).

In addition to these four principles, in clinical terms an overarching concept of best interest operating alongside the principles of non-maleficence (thus functioning similar to a weaker form of the Harm Principle) is applied to patients who are unable (i.e. incompetent) to make choices for themselves, due to their condition, particular illness or limited cognitive capabilities (Nardo et al. 2019, p.2). The purpose of principlism is therefore non paternalistically to promote the best interest of the patient, through avoiding unjustified harms and advocating benefits through effective patient support, treatment, and fair access to medical resource (Nardo et al. 2019, p.2). In so doing it combines and deploys both consequentialist and deontological concepts in a complimentary manner, in order to establish greater levels of debate, and arguably more informed decision-making (Beauchamp and DeGrazia 2004, p.57; Beauchamp and Childress 1979). Principlism is therefore often considered as a 'hybrid' applied ethical framework, uniting the best elements of ethical theories that are compatible with most societal, individual or religious belief systems (EFS 2018; Beauchamp and DeGrazia 2004). This approach to applied ethics consequently is an exemplar for the way in which this study is conducted. Nevertheless, it does not mirror the equality of principles approach that principlism is said to aim at. Although its major focus is consequentialist (in order to determine the benefits and disbenefits of using nanotechnology within elite sport) it draws upon deontological concepts when useful, in order to consider the morality and regulation of nanotechnology within elite sport. Therefore the adoption of such a 'hybrid' approach will add value to this research, through providing greater insight into the ethical and moral considerations of using nanotechnology in sport, helping to informing potential regulatory requirements.

9. Conclusion

This chapter began by introducing the three-nanotechnological case studies that will form the basis of this research, each of which relate to a key area of sports engineering, along with a third-party application. Each selected-on grounds of originality, offering the potential to explore new areas of academic research in relation to the ethical impact nanotechnology may have on elite sport. Conversely, limitations were also presented concerning the number of selected case studies, range and depth. Once addressed, this was then followed by an extensive consideration into which ethical approach would be most suitable in order to analyse each of these case studies, with an applied ethical approach selected. Due to the lack of evidence currently available in order to conduct such an applied approach, an additional argument was presented for an ethical analysis of the case studies via a consequentialist approach. This will be used to establish such evidence in order to inform an applied ethical discussion of the findings that will take place later in this research. This principle therefore has many benefits, offering a universal nature and impartial standpoint, and despite its limitations, still offers a best fit for the analysis of the case studies. Enabling an exploration of the consequences of each application of nanotechnology within elite sport in order to determine the best course of action moving forward in a domain with a distinct lack of regulation at present. However, despite a consequentialist framework being adopted, it was also argued that this work would not disregard the value of deontological concepts, and where useful to aiding debate, such issues would additionally be addressed. Consequently promoting a 'hybrid' approach to an applied ethic.

This chapter has therefore laid an ethical framework for the next three chapters of this research; where each case study will be offered an overview of the nanotechnological applications within their given context, as well as a consequentialist analysis of the potential benefits/disbenefits that may be generated via their use. The first case study to be ethically analysed will be nanotechnology's application to an enabling technology, that being the race bike.

Chapter 5 - Case Study One: The Application of Nanotechnology to Enabling Technology

1. Introduction

The sport of cycling has formed a close relationship with sports engineering, relying on it to further not only a cyclist's levels of performance, but also safety both in and out of competition. This can clearly be demonstrated when considering the race bike, which has undergone significant modifications since its humble beginnings. Cycling has therefore greatly benefited from the work carried out by sports engineers, complimented by significant investments made by manufactures in relation to research and development within the sport; resulting in the regular emergence of new enabling equipment, ensuring that cyclists have consistent access to cutting edge technologies in order to gain a potential edge over their competitors. This is clearly evidenced when considering the sport's more recent attempts to apply nanotechnology to cycling equipment; perceived as being a potential 'game changer' to the domain, as well as a modern replacement for the highly successful material technology of carbon fibre.

This chapter will consider the recent integration of nanotechnology into cycling at the elite level, with a specific focus on the road bike. The following discussions will consider why and how this technology is being increasingly used in road bike design and construction, and will consider the potential ethical impacts it may have in terms of benefits/disbenefits. It will further consider both the individual cyclist, alongside the sporting system as a whole. To begin, this chapter will initially explore a brief history of the bike, followed by a consideration as to how previous technologies have impacted cycling; seeking to establish an essential knowledge context that will inform later discussions in this chapter.

2. A Brief History of The Bike

The road bike is one of the most successful modes of transport of all time, with a long and evolving history. First introduced into 19th Century Europe, the bike has many innovators credited to its name, but Baron Karl von Drias is considered to be the first, developing a primitive model in 1818 known as the Dandy Horse, or the 'running machine', requiring the rider to propel themselves through the action of pushing their feet along the ground (Brown 2008). This early design was then enhanced upon later in 1839 by Kirkpatrick MacMillian, who integrated a mechanical crank drive to its design, allowing the rider to move the bike via reciprocating movements of the rider's feet on the pedals (Sedycias n.d.). This consequently established the foundations for what is now considered the modern road bike, however it was not until 1870 where Pierre Michaux and Pierre Lallement developed the velocipede; a high seated and big front-wheeled bicycle constructed from wrought iron with rubber tyres, that the wider public were able to access this mode of transport due to its mass production (Boardman and Sidwells 2015; Sedycias n.d.). Despite the success of the velocipede, it did have a number of design flaws, such as its poor weight distribution, making it challenging to ride. This led to a redesign in 1885 by J.K Starley's, who developed the Rover, which had evenly matched wheels and a proper seat (Sedycias n.d.). This version of the bike is now considered as the first modern road bicycle, as it had a number of recognizable features that we expect to see today, including a diamond shaped frame; pedals below the saddle that power the back wheel through a chain and gears system; handle bars that moved the front wheel; and forks supporting the back wheels (BM 2014).

The road bike soon became an essential mode of transport, offering a cheap form of social mobility, allowing people to easily travel from one place to another. Further, it also became a prominent form of recreational activity for the masses. In France for example, indoor cycling academies soon emerged all over Paris, with the first ever documented road race also held in Paris, and won by an Englishman James Moore (Boardman and Sidwells 2015). Consequently, interest in the sport of cycling quickly expanded and spread around the world, with an ever-increasing number of races and competitions being held across each year in differing locations.

As cycling entered into the modern era, driven by ever increasing levels of professionalism within the sport, the design and construction of the road bike radically improved, marking a shift away from being a simple mode of transport to a finely tuned piece of performance equipment. The result of which saw a movement away from more traditional construction materials such as steel and iron (which were heavy and lacking in flexibility) to those of titanium and carbon fibre (Fiedler 2017). This consequently offered cyclists benefits such as reduced weight, along with increased strength and flexibility (Fiedler 2017). Moreover, the application of new technological innovations also began such as shifters and derailleurs, allowing riders to work quickly through a range of gears so that they could go faster on flats/downhill's and climb steeper hills (Fiedler 2017).

Yet much in the same way as any other sport, the equipment utilised within professional cycling is regulated, undertaken by the Union Cyclist Internationale (UCI from now on). The UCI produces a set of rules for the development and use of equipment within the sport known as the *UCI Technical Regulation* (UCI 2017). This outlines the requirement that teams, manufacturers and athletes must follow when constructing and modifying race bikes for use in competition (UCI 2017). The *Technical Regulation* sets out governance for a wide variety of technical points, examples including a weight limit of 6.8kg, size limits on frames/wheels/handlebars, and a bar on the modifications of road bikes to include motors, as the athlete must always propel themselves (UCI 2017). In addition, the UCI has also deployed the Lugano Charter with the aim of protecting the spirit and traditions of the sport, ensuring that the design of the bike remains 'user friendly' and that the efforts of the athlete remains of pivotal importance, as opposed to the strength of the technology that they are using (UCI 1996).

3. Impact of New Construction Materials on Cycling Performance

The application of material engineering has had a significant impact on cycling, aiding levels of performance and safety within the sport. Further, its application by sports engineers has been allowed to flourish due to the current lack of material regulation that exists within its technical regulation. If a bike therefore conforms to the rules outlined in the UCI *Technical Regulation* (2017) *and* is also in alignment with the *Lugano Charter* (1996), then the materials used in its construction are of little relevance. Consequently, cyclists, teams and organisations are continually looking for new and innovative materials in which to design and construct new road bikes, with the aim of improving not only athletic performance, but also its safety.

Cycling has consequently undergone significant evolution in relation to the materials in which race bikes are constructed from. In previous years, metal was predominately used for bike construction, with iron and steel proving most popular due to the strength that they offered the rider (Fiedler 2017). Yet due to research conducted by sports engineers and manufactures, these metals were subsequently replaced by newer metals such as aluminum and titanium due to their improved strength and reduced weight (Fiedler 2017). Despite the benefits that aluminum and titanium offered both in terms of weight reduction, strength and flexibility, sports engineers continued to explore alternative construction materials that could be used to further enhance a bike's performance and safety levels. One such example of this is evident in 1960s via the Bowden Spacelander, which was the first bike constructed from an all fibreglass frame; offering superior benefits to metal, such as improved strength/resilience, stiffness, corrosion prevention and impact resistance (R-TECH 2017; Craftech 2019). However, despite these advantages, the manufacturing processes of a fibreglass frame proved to be expensive, resulting in considerable commercial cost, with few athletes and teams investing in it - only 544 were ever sold (R-TECH 2017).

Despite this set back, it was not long until another new material came to prominence, that being carbon fibre in the 1980s (Murnane 2017). Due to its advanced properties, such as its reduced weight, increased strength, and ability to be aerodynamically sculpted, it soon became (and still is) the material of choice for the construction of race bikes (Murnane 2017). Moreover, due its improved stiffness and flexibility as a material, it was soon favoured by elite cyclists, as it maximizes the degree in which the power they produced could be successfully transferred to the drive train, making it easier to propel the bike forward (Murnane 2017; Newcomb and Chae 2018). The first use of carbon fibre within elite cycling took place in 1989, with the Look KG86 race bike, combining Carbon Tubes (CT from now on) with Kevlar layers of woven carbon fibre in the construction of its frame (Bridgewood 2018). This bike was the first carbon fibre production frame, made famous by Greg LeMond who won the Tour De France using it during its first year of production (Bridgewood 2018). There were of course, multiple factors that resulted in LeMond's success, but his bike certainly presented him with a number of significant benefits. The main benefit being its weight at around 1Kg lighter than the aluminum bikes used by his competitors, consequently supporting him to a final eight-second tour victory (R-TECH 2017). Despite LeMond's success using such a bike, not all cyclists converted to carbon fibre immediately; this was due to the initial concerns surrounding the production of carbon fibre, where a number of poor quality bikes were being produced, which put the safety of a cyclist at risk (R-TECH 2017). These concerns were subsequently resolved via improved manufacturing processes, and further promoted by Lance Armstrong who rode a new and improved carbon fibre Trek 5500 OCLV bike to success in the 1999 Tour de France, making the material essential for any competitive elite cyclist going forward.

Since its introduction and proliferated use within the sport, carbon fibre has had a significant impact on athletic performance. This impact can be seen when considering the 4-km individual pursuit, as prior to carbon fibre frames, the average speed of this race in the 1900s was around 40km.h (Hakke 2009). After the integration of carbon fibre to bike frames this increased to 49km.h in the 1980s (Hakke 2009); which may appear only a marginal improvement, yet at the elite level within cycling this is significant due to the fine margins of success at the top level. The 4-km race consequently underwent a 24% performance improvement between 1964 and 1996 due to advancements in aerodynamics related to the integration of carbon fibre frames (Hakke 2009). This impact could also be shown in the one-hour event, undergoing a performance improvement of 220% over 102 years, with 101% again being the result of improvements in aerodynamics brought about by new technologies such as carbon fibre frames (Hakke 2009). Further, due to these frames being 32% lighter, 25% stiffer and 20% more aerodynamic than their metal predecessors, it also allowed cyclists to go 0.5km/h faster for the same energy output (R-TECH 2017).

4. Nanotechnology and Elite Cycling

Despite the success of carbon fibre within cycling, sports engineers are still continuing to search for new and advanced materials in order to further improve the design and construction of race bikes. Consequently, nanotechnology is now being viewed by many within the sport as the potential future of race bike construction. This has resulted in manufactures and engineers within cycling starting to integrate nanomaterials such as graphene and CNTS into the construction of new race bikes. For example in 2006, the winner of the Tour de France Floyd Landis rode the first example of a 'nano' bike, which was infused with CNTS in the resin of the frame (Robinson 2016). The companies behind this bike, BMC and Easton Sports, therefore recognised the early potential of nanotechnology's use for bike construction, inspiring others to follow suit such as Dassi, who deigned and produced the Interceptor (R-TECH 2017; Robinson 2016). In addition to bike frames, nanotechnology is also being applied to tyres, with Vittoria (who have invested 45 million euros already into the technology) now integrating nano synthetic silica into their range of Martello and Mota tyres that are popular amongst athletes at the elite level (Van Schalk 2016). This is due to the benefits that this technology offers in relation to producing faster road speeds, shorter stopping times and lower road resistance (Benson 2017; Van Schalk 2016).

Nanotechnology's use within cycling is also going beyond its sole application to the bike itself, with companies like Catlike integrating graphene into a range of *Mixino* helmets in order to increase strength and therefore safety (Glaskin 2015; Castelli n.d.). Additionally, Castelli developed a jersey treated with nanofilaments to increase its water repellence (Glaskin 2015; Castelli n.d.). Nanotechnology is therefore already playing a role within elite level cycling, and this is only likely to increase going into the future, driven by our ever-improving knowledge of this technology.

5. Ethical Benefits and Disbenefits of Using Nanotechnology in Cycling

Despite nanotechnology still being in its early research and development stages, it is already increasingly prevalent within elite cycling. However, in order to determine whether its integration will be beneficial or not, it is first essential to ethically consider its potential benefits and disbenefits through the application of the previously agreed consequentialist ethical framework. The following table explores the key points that will be ethically debated throughout the next section of this chapter:

Table 2: The benefits and disbenefits of using nanotechnology in elite cycling

Benefits for the Athlete	Benefits for the Sport	Disbenefits for the Athlete	Disbenefits for the Sport
Improved Levels of Performance	Increased Spectator Engagement	The Best Athlete May Not Win	A Challenge to the Spirit of Cycling
Increased Levels of Safety	New Financial Opportunities	Financial Fair Play and Equal Access	Manufacturing Concerns

6. Benefits for the Athlete

6.1 Improved Levels of Performance

Much like the initial integration of carbon fibre in the 1980s, nanotechnology is also demonstrating the potential to improve performance levels within elite cycling. The emergence of new 'nano' bikes such as the Dassi Interceptor (with its graphene frame) are both lighter (750g) and stronger (150 times stronger than steel) than carbon fibre bikes, and considerably more aerodynamic due to ease of graphene manipulation (Sexty 2017; Glaskin 2015; Busca 2016). In addition, graphene acts as shock absorber, reducing road noise and promoting a more comfortable ride, both of which support a cyclist's performance within competition (Sexty 2017). Thus, nano frames could offer cyclists a number of potential performance benefits, as the reduction in weight allows for less energy to be lost when pedaling, promoting a more direct energy transfer, essential when hill climbing for example. Also, due to the improved strength and flexibility of the frames, a cyclist is able push harder, enabling greater speeds to be achieved without having to expend the same amount of energy or worry about whether the frame may crack, a current issue with carbon fibre frames (Murname 2017). Finally, due to graphene being an excellent electrical conductor, it may be possible to re-introduce electrical gear shifting technologies, allowing for quicker gear changes overall, again improving performance levels (R-TECH 2017).

Tyres constructed from nanomaterials are also presenting the potential to boost a cyclist's performance levels. Graphene tyres such as those manufactured by Vittoria for example, are already reducing rolling resistance and puncture rates, with independent tests demonstrating that they provide a 32 second advantage over the older non graphene Corsa tyres (Rossiter 2017). It is evident that they are also presenting a significant reduction in rolling time, up to 20.7% less in comparison to older forms of tyres (Van Schalk 2016). For an elite cyclist this is substantial, especially as the margins between winning and losing are slim. Graphene tyres for example, are also able to generate greater lateral stiffness, producing 10% more heat dissipation whilst also being 15% lighter; all of which again aid improved levels of performance, allowing for greater speeds to be reached and maintained throughout a given race (Hovenden 2016).

6.2 Increased Levels of Safety

Cycling is an inherently dangerous sport, where high speeds are reached across often increasingly more complex courses. This may be evident when considering the Tour De France, where athletes are able to reach speeds of 25 to 28 mph on the flats, and 21 to 25 mph in mountainous terrain (Stein 2011). Or in the Tour de Suisse, where the decent off the Simonplass can see riders reaching speeds of more than 130kmh (80mph) making it one of the fastest and most dangerous descents in the sport (Robertshaw 2017). Therefore, as cycling becomes increasingly fast, the risks for the athlete also increase, with crashes becoming more commonplace particularly in poor weather conditions (Fotheringham 2017). Engineers and the UCI (2017) have emphasised the importance of safety within the sport, ensuring that cyclists are protected from as much risk as possible. This has resulted in the emergence of new safety equipment over recent years, with examples including the clip less pedals, allowing cyclist's to rapidly release from their bike during a crash, along with crash helmets, offering internal reinforcement, with a mold usually constructed from a polymer foam able to absorb considerable impacts (Bridgewood and Hovenden 2015; Granta n.d.)

Nanotechnology offers the potential to further improve safety standards within cycling; an example of this may be seen when considering the bike frame itself. At present, most bikes at the elite level are still constructed from carbon fibre, yet carbon fibre does have a number of safety drawbacks. Unlike its predecessors it is brittle as a material, and often damage made to the frame itself is not visible due to the fact that integral bonds can be broken, whilst external layers still look intact (Murnane 2017). This can result in a weakened frame that can fail without warning, putting a cyclist at serious risk, especially when they are travelling at high speeds (Murnane 2017). Furthermore, unlike aluminum and steel, carbon fibre does not bend in crashes, but instead shatters; often resulting in riders being thrown across the road/track and increasing their chances of serious injury (Austen 2014). This is due to poor design, where manufactures seeking to use carbon fibre to make bikes thinner and lighter mean that when stressed beyond its limits, it fractures into many pieces (Austen 2014). This is where graphene frames could offer improved levels of safety, as it is has a tensile strength of 130 gigapascals, making it 2000% stronger than the toughest carbon fibre, and is far less brittle in comparison to hi-modulus carbon (Levitch 2015). A graphene composite should theoretically be able to absorb an impact better than a carbon fibre, reducing the potential of shattering when under strain, and therefore the potential for injury (Levitch 2015). Graphene is also able to dissipate heat effectively, allowing for improved breaking performance in comparison to carbon fibre, again promoting the safety of the cyclist (R-TECH 2017).

The application of graphene to tyres may help to promote safety within cycling via nanotechnology, as discussed previously in this chapter. Companies such as the aforementioned Vittoria are implementing cotton casting and graphene in their tyres in order to improve levels of grip, as the graphene nanoplates support the rubber whilst under intense braking friction; thus, helping to prevent it from deforming when taking bends at speed, and reducing the potential of the bike sliding away from the cyclist (Gibbons 2016). This enables improved traction between the tyres and the road, reducing the possibility of crashing and therefore injury to the cyclist. Nanotechnology may also reduce the chances of a puncture, not only helping cyclists in terms of their performance, allowing them to continue to ride for longer (Gibson 2016); but also their safety, as significant punctures can cause tyres to rupture, often resulting in crashes which could be potentially life threatening when travelling at high speeds. The graphene aids the rubber in closing any small holes which may occur as a result of foreign objects, consequently reducing the chances of punctures overall (Gibbons 2016).

7. Disbenefits for the Athlete

7.1 The Best Athlete May Not Win

Sport is an inherently competitive activity, with athletes and coaches continuously striving for new and innovative ways in which to improve levels of performance to gain an edge over their competitors. This drive is also what makes it interesting for spectators, as they are entertained by the fierce battles that take place between equally matched athletes within a competition. Yet despite this, even the most hardened fan of any sport still wants to see a fair competition; as opposed to witnessing the success of their favoured athlete via methods of cheating or technological enhancement (James 2010). This is evident when considering dialogues with the public in relation to the use of technology within sport. Concerns were raised that new technologies may enhance an athlete's ability beyond what they have earned through hard work and the application of skill, therefore preventing the 'best' athlete from winning (James 2010). Thus, the athletes may be evenly matched, but the technology is determining the winner through the micromanagement of performance levels, which some hold would devalue the purpose of a given sporting competition. This concern has also been raised by cycling fans, who in a recent survey by the UCI have found that fans would like each rider to have fewer technical advantages within each race (Ostlere 2019a).

Similarly, concerns raised such as this may for example relate to the use of advanced materials for the construction of bikes. The application of materials such as carbon fibre have proven to offer cyclists a number of benefits as previously discussed; promoting improved levels of overall performance, which arguably has not been gained through a cyclist's individual hard work and efforts (Hakke 2009). Moreover, if you were to consider LeMond's eight-second record-breaking victory in the Tour de France, it does raise the question as to whether he would have been as successful if his competitors also had access to a carbon fibre bike, such as the equally matched Laurent Fignon (R-TECH 2017). Although this is a hypothetical question, it does emphasise the role that material technology such as this had in supporting LeMond's success. This has consequently generated concerns regarding the increasingly blurred line within the sport between man and machine, where the strength of the technology rather than that of the athlete is determining a cyclist's potential for success in competition more prominently.

The application of nanotechnology to elite cycling may generate a similar concern, as much like the early introduction of carbon fibre to cycling, this technology is also offering cyclists a number of performance benefits. For example, the application of graphene to bike frames and tyres is already demonstrating an ability to improve performance levels by increasing a cyclist's speed and reducing lap times. Furthermore, graphene infused tyres could also reduce the skill required by riders to avoid potential foreign objects when riding at high speeds, essential for avoiding punctures and injury. Technology such as this may therefore take greater risks due to the added support that this technology may offer. It could therefore be very influential, particularly as the margins between winning and losing are often fine at the elite level. Moreover, it is fair to say that application of the right technology may enable even the worst rider in a peloton the potential of winning, actively closing the skill gap that exists between athletes at this level. As we enter into the future, this issue is only likely to be further exacerbated, especially if nanotechnology continues to become more prevalent within the sport.

7.2 Financial Fair Play and Equal Access

The application of nanotechnology within elite cycling also generates issues concerning financial fair play and equal access due to funding gaps between athletes. This therefore generates a problematic performance disparity between the 'haves' and the 'have not's', which in road cycling is still a particular issue. This is due to an increased number of elite cycling teams now owned by private enterprises or business people, a consequence of strained financial times within sport (Pender 2018). Examples include Ineos (originally Team Sky) owned by Britain's richest man Sir Jim Ratcliffe, offering the team considerable investment opportunity (Whittle 2019); as well as Mitchelton-Scott, currently bankrolled by Gerry Ryan, who is estimated to have committed £20 million into the team in order to support its further progression (Pender 2018). The involvement in cycling by those such as Sir Jim Ratcliffe has raised considerable concern in relation to unequal financial resource (commonly known now as 'financial doping'[11]) in comparison to other teams within the sport; putting them at a disadvantage when it comes to funding and access to technological resource (James 2010; Schubert and Könecke 2015).

This could be particularly relevant when considering nanotechnology's application to elite cycling, as at present, the cost of graphene for example is still very high due to existing challenges relating to its mass production (McLeod 2017). Thus, at present, nano bikes have a high commercial value, with those such as the Dassi Interceptor costing around £12,000, where the frame alone costs £5,995, making it one of the most expensive bikes in commercial production (Sexty 2017). High cost such as this could limit the number of cyclists who belong to teams that are able to exploit cost-related benefits in order to aid their team's performance in a given race. This could consequently further exacerbate an already prevalent financial issue within cycling, with the 2019 Tour de France having been dominated primarily by four teams such as Quick-Step Deceuninck and Team Ineos, holding the biggest budget of any World-Tour team of more than £30m per year (Ostlere 2019a).

This has been further reinforced by fans of the sport, who want to end the dominance of the richest teams such as Team Ineos (formerly known as team Sky) according to an in-depth survey carried out by the UCI (Ostlere 2019a). The survey considered the views of 22,000 fans from 134 countries, asking their opinions on the sport with a particular focus on stage racing and grand tours like the Tour de France (Ostlere 2019a). The findings of which found that more than 'three-quarters of respondents said differences in budgets has an impact on the appeal of road cycling, and 62% said

[11] The issue of 'financial doping' is further discussed and clarified in Chapter ten.

a limited number of teams hiring the best riders makes racing too predictable' (Ostlere 2019a, para.3).

The high cost of cycling equipment containing nanotechnology could additionally have a knock-on effect to participation levels within amateur cycling. This is because it is only likely to further increase the financial requirement that is required for a cyclist to potentially break through to the elite level (James 2010). Hence, further intensifying an already challenging financial situation within amateur cycling, whereby a full season of racing can cost up to £25,000 to complete after taking into account training camps, equipment, race fees and nutrition amongst other factors (Critchlow 2015). This has already had a detrimental impact on cycling's image, with many regarding it as a 'rich man's' sport, where success requires 'deep pockets', deterring many young people from taking it up as a sport (Klopp 2014).

8. Benefits for the Sport

8.1 Increased Spectator Engagement

The emergence of new technologies has not only been essential in supporting the individual cyclist, but also the sport as a whole, particularly in relation to spectator engagement. This is due to the fact that the modern spectator expects to see the integration of new and cutting-edge technologies in order for a given sport to remain interesting. Further, most spectators take pleasure in watching elite athletes use such technologies in order to reach new levels of performance within their sport, heightening the entertainment value for the observer. Cutting edge technologies also aid the media spotlight of a given sport; raising its public profile and ensuring that it remains fresh in the ever-changing sporting world; essential for its continued long-term success (James 2010). Thus, without said development sport could be at risk of stagnation, and become irrelevant in the eyes of the spectator; resulting in financial and spectator loss, whilst reducing its viability as a sport moving forward (James 2010; IME 2012).

New technologies therefore generate spectator appeal, something that cycling has been effective at over the years by regularly introducing advanced technologies via equipment used within the sport in order to promote performance and safety. The integration of new technologies such as carbon fibre have resulted in new levels of performance ascertained, generating greater spectator enjoyment and engagement, as people want to see records broken and greater speeds attained (IME 2010; James 2012). Thus, enabling cyclists to reach new levels of performance previously not thought possible. The application of nanotechnology at the elite level is only likely to promote this notion further, with the hope that cyclists reach even greater levels of performance; pushing the boundaries of the sport to new heights in order to maintain engagement from the ever-demanding modern spectator. This could therefore work to draw new spectators to this sport, in turn keeping cycling relevant in the ever-evolving sporting industry.

8.2 New Financial Opportunities

The success of an athlete and their accompanying technology can also have a positive impact in relation to the financial revenue of sport. This is clearly evident in cycling, where the success of a cyclist or cycling team can inspire others to take up the sport, and moreover result in them spending money on new (and often costly) cycling equipment. For example, the success of the British Cycling team in the 2012 Olympics meant that the number of people that took up the sport dramatically increased, especially by parents who supported their children with their desire to emulate their heroes, and participate in the sport (BC and SKY 2012). This also increased consumer spending on cycling, with companies such as Halfords identifying an increase in sales, mostly driven by the demands for premium elite bikes and children's bikes (BC and SKY 2012). There was again a spike in the sales of premium bikes and equipment when Bradley Wiggins won the Tour de France in 2012, especially amongst the recreational and amateur cyclist hoping to emulate the success of Wiggins in their own time (Brignall 2012; BC and SKY 2012). Moreover, Chris Froomes 2017 Tour De France win also generated increased sales in elite style bikes, with online sellers recording a 25% increase in sales, along with specialist companies such as Evans witnessing an increase of consumers purchasing high end bike models containing carbon fibre (Goldfingle 2016).

There is therefore a clear link between cycling success and increased equipment sales; a trend only likely to be replicated once cyclists start gaining success using 'nano' bikes. This technology will present a number of new financial opportunities for cycling via the development of a new product range of elite road bikes (along with other affiliated equipment), which consumers are likely to invest in. Further, consumer analysis has revealed that there has been a market growth in the last few years for sporting equipment considered innovative and cutting edge, with consumers willing to pay more if it offers not only functional performance advantages, but also style appeal; supporting their own recreational pursuits (Harifi and Montazer 2015). This again could result in a potential increase in the sales of 'nano' bikes and accompanying nanotechnological cycling equipment such as clothing; supported by UCI (2017) regulation, as all bikes and equipment used in competition must also be made available on the commercial market. The potential for commercial success such as this could therefore generate increased financial return that may then be redistributed back into the sport via various means, such as sponsorship and research and development costs.

9. Disbenefits for the Sport

9.1 A Challenge to the Spirit of Cycling

For some, the ever-increasing integration of modern technology within cycling has challenged the spirit and nature of the sport, increasingly blurring the existing fine line between man and machine. New and cutting edge technologies shift the focus of the sport from the strengths of the cyclist, to that of the technology itself - hence, it may therefore be argued that its integration into cycling is increasingly undermining its spirit and purpose; transforming it into a 'technological arms race', where the winner is increasingly determined by the equipment they are using, rather than their efforts, hard work and skill. Clearly a concern within the sport, the Lugano Charter (1996) has been applied with the aim of reminding manufactures, athletes, and teams of the traditions and spirit of the sport; where race outcomes should be a result of the cyclist’s efforts, and not the technology itself (UCI 1996). It also stresses the point that technology should not impose its own logic on the sport, with new prototypes identified as distancing themselves from reality, and performances determined more by the man-machine relation, rather than the qualities of the rider; thereby going against the true meaning of the sport (UCI 1996).

However, despite such attempts to regulate and maintain the spirit and traditions of the sport, technological innovation still continues to represent a challenge, with some arguing that it makes the sport easier, reducing the need for the application of effort and skill (James 2010). This argument undermines the purpose and nature of cycling, because for some, athletic performances can only be really appreciated if they are produced from hard work, and if they are aided by technology, this requires less work and consequently success in a given competition holds less value (James 2012). The continued application of nanotechnology is only likely to exacerbate this issue further due to the performance benefits that it is already starting to offer, again putting greater focus on the strength of the technology as a determiner of success within races conducted by often equally matched competitors. Thus, promoting additional methods of micromanaging performances. For example, the further reduction of weight and increased strength offered via the integration of graphene to a bike frame could work to reduce the effort a cyclist is required to apply in order to propel the bike forward and reach a top speed. This would allow an athlete to store more energy throughout the race in comparison to other athletes, which could end up being the difference between winning and losing when they reach the final sprint to the finishing line. Further, the application of nanotechnology to cycling could also be seen as a challenge to the Lugano Charter (UCI 1996), as it unsettles the man-machine relationship, allowing the technology to impose greater impact upon the sport. It also works to further alter the bike from a traditional mode of transport to one only used by the elite, creating continued division between old and new traditions within the sport.

9.2 Manufacturing Concerns

The integration of nanotechnology to cycling equipment also raises concerns over its safe and ethical manufacturing, known as nanomanufacturing[12]. This process has already raised a number of concerns regarding the potential risks it may present to the health of those working with it at the production line level (OECD 2012). We already have a good understanding of the potential risks that traditional sized chemicals and materials may present to humans, however, this knowledge cannot be easily transferred on a nanoscale (OECD 2012). There are two main reasons for this; the first is due to the small size of engineered nanoparticles (between 1 and 100nm), which presents unique physical and chemical properties in comparison to their bulk counterparts, consequently reducing our ability to predict how they may interact with human physiology. The second is due to the large surface area of engineered nanoparticles, which increases their reactivity as well as their potential to absorb toxins and transport them around the body, which could intensify potentially harmful effects (Nanowerks n.d.; NIOSH 2009).

Recent studies carried out on animals and human workers exposed to nanomaterials seem to support such concerns; and have identified that the unique size of nanoparticles allows them to enter the body via a number of different channels, such as through the respiratory system, skin or mouth (NISOH 2009). Once in the body, these particles have demonstrated the potential to cross major bodily systems such as the blood brain barrier, which could be incredibly dangerous as 'nanomaterial's have proved to be toxic to human tissue and cell cultures, resulting in increased oxidative stress and inflammatory cykotine production' (Madhwani, K 2013, P.88). To exemplify this, experimental studies on rats have indicated that 'mass doses of insoluble incidental nanoparticles are more potent than large particles of similar composition in causing pulmonary inflammation and lung tumors' (NIOSH 2009, P.V). Furthermore, studies completed on those working to manufacture aerosols who are regularly exposed to nanoscale particles have been found to demonstrate early signs of adverse lung effects such as fibrotic lung disease (Madhwani, K 2013, P.88). Moreover, the results of studies conducted in order to consider the effects of silica

[12] The process of manufacturing nanomaterial's is known as nanomanufacturing, and this involves the use of scaled-up, reliable and cost-effective manufacturing of materials, structures and devices (NNI, n.d.).

nanoparticles on macrophage inflammatory responses also suggest that silica particle size impacts immune response, with submicron silica particles including higher inflammatory responses than silica particles over 1000 nm in size (Kusaka et al. 2014). Hence, these studies (although more still needs to be done to ensure consistency and reliability of results over time) suggest that exposure to nanoparticles may pose a health risk to those working at the manufacturing level, particularly when exposed to nanomaterials in a raw or dust like state (Madhwani 2013). Despite this, it must be made clear that there is currently no consensus within the scientific community over which characteristics are most important in understanding the dose-response relationship for each type of nanomaterial, mainly due to the infancy of the technology, and the broad range of results that have been received from studies to date (Clark 2011a).

There are also workplace safety fears associated with nanomanufactuing, for example, this form of manufacturing increases the chances of workplace fires, especially if nanoparticles are free in the air. Combustible materials at the nanoscale are far more reactive due to their increased surface area than coarser materials with a similar mass concentration (NIOSH 2009, P. viii). This means that they are much more likely to react unpredictably and present a significant flammable hazard to those working with said materials, especially if already working in existing hazardous conditions. Further, the potential cutting and grinding actions may release breathable – sized nanoparticles into the air, which could again increase the potential for fire hazards, whilst also posing additional health risks (NIOSH 2009, P. viii).

The manufacturing of nanotechnology for sporting purposes presents another major concern in relation to environmental risk. Although at present there is no substantial evidence that engineered nanoparticles pose a significant risk to the environment (much like concerns relating to its impact on human health) due to the existing knowledge gap that currently exists when considering how nanoparticles may interact with the environment. This lack of knowledge should not be interpreted to mean that there are no risks, or that the lack of evidence implies safety. At present we are unsure as to how to effectively dispose of engineered nanoparticles, and have little idea as to how they may impact the environment in the long run (NanoTrust 2012; Biddlecombe 2015). We are however at present aware that nanoparticles are highly persistent, meaning that once they are in the environment, it is hard to remove them (Biddlecombe 2015). Consequently, nanotechnology presents a number of potential risks to the environment, which if not effectively addressed through further studies, could result in long-term irreversible harm due to our lack of awareness. Moreover, due to graphene playing such a significant role in the development of new equipment in relation to this case study, it’s worth outlining that it also presents potential issues for the environment, which are as follows:

- *The toxic property of graphene is unknown, and is difficult to remove from waste.*
- *Graphene could react with materials and biological systems in the environment in a way that is unexpected.*
- *Graphene has a good thermal conductivity, and fire retardancy of the polymer nanocomposites is already well researched. However scientists warn that it may cause a fire risk if graphene is contaminated with other substances during the process* (Zhang et al. 2016).

It is therefore clear that nanotechnology generates a number of early warning signs in relation to human health and the environment. All of which, although not yet fully supported by evidence, must be taken into consideration in order to ensure the safety of both human life and the environment.

A question could be raised at this point as to whether such concerns are relevant to cycling, as arguably they could be seen as a manufacturing health and safety issue. Although a valid point due to the fact that a concern such as this is unlikely to have a direct impact on cycling, it still could generate a problem for the sport with regards to negative association[13]. For example, if the health of those working to produce such equipment becomes compromised, or an industrial accident takes place, then it could significantly damage the image and reputation of cycling manufacturers, and potentially the sport as a whole. This may be particularly relevant if it emerged that risks were identified but ignored in favour of progress and financial return; demonstrating a willingness of key stakeholders within the sport to put a technology's development above and beyond that of human welfare in the pursuit of improved performance levels. This could result in a potential loss of financial revenue for both the sport and manufacturers, with cyclists, teams and spectators

[13] Additionally, such a concern relating to the risks associated with manufacturing is important, as it is an example of a potential indirect outcome of nanotechnology's application to cycling. Consequently, being an ethically relevant point within a consequentialist analysis such as this.

refusing to use such technology, and even turn away from the sport as a whole. Thus, if cycling manufacturing companies are going to pursue the inclusion of nanomaterial's into bike frames and tyres for example, considerations must be made with regards to the health and safety of the workers involved in the production of such products.

Issues such as those discussed above have already proven problematic for other sports, and have had detrimental effects on their image. An example of this can be seen in horse racing, where questions relating to animal welfare are continuously raised, and have resulted in a decline of followers to the sport. Yet it's not just sports that have faced issues such as these, manufactures have also been challenged with human welfare issues similar to this. Nike being one of the most famous examples, who during the 1990s were accused of breaching human rights and slave labour laws through their use of sweatshops in countries such as Vietnam (Nisen 2013). Observed as putting profits before human welfare, and consequently frowned upon by the international community. This resulted in Nike's image being tarnished, reducing sales and contract endorsements (Nisen 2013). Yet despite the fact that Nike has now managed to put these issues behind them through a lengthy process of transparency and commitment to human rights, it has not been forgotten, and has taken some time for the brand to rebuild its reputation as an ethical company. Issues such these are significant, and cycling must take careful consideration to avoid replicating them in future in order to uphold its image and reputation.

10. Conclusion

Enabling technologies have become vital to the continued development of the modern elite athlete, helping them to reach new levels of performance and safety. Hence, teams, athletes and coaches are increasingly turning to sports engineers in order to improve the equipment they use, with the aim of boosting their chances of success in a given competition. This is clearly evident when considering cycling, a sport that relies on an enabling technology in order to be a sport in the first place. Consequently, technological advancements have become paramount in improving levels of cycling performance, as clearly demonstrated through the application of carbon fibre to the design and construction of bikes in the 1980s (Hakke 2009). Yet in recent years, nanotechnology has become increasingly more prevalent within cycling, and is already offering cyclists and the sport as whole a number of benefits, such improved levels of performance, safety, spectator engagement and financial opportunities (Robinson 2016). On the contrary, nanotechnology also presents the sport a number of disbenefits, such as issues relating to health/environmental concerns, financial fair play, unfair enhancements and potential sporting image damage. All of which have to be equally discussed and considered, especially with the continued integration of nanotechnology into the sport of cycling at present.

Now that I have ethically considered some of the potential benefits and disbenefits of nanotechnology's application to an enabling technology, the next chapter will ethically consider the second of the case studies, the application of an embedded technology to elite sport, in the form of the nanobiosensor.

Chapter 6 - Case Study Two: The Application of Nanotechnology to Embedded Technology

1. Introduction

The field of performance analysis has fast become an essential element to the success of the modern-day elite athlete[14]. It has allowed for vital data to be reviewed in order to enhance performance levels, thereby increasing an athlete's chance of success in competition. As a consequence of its ever-growing importance in elite sport, the field of performance analysis has undergone significant evolution, driven by an ever-growing demand for new levels of performance data and analysis techniques. This has resulted in the integration of a number of new technologies for performance analysis purposes, one of which being the biosensor. A device which has allowed for an athlete's biological data to be collected, tracked and reviewed by coaches and teams, in order to establish bespoke training packages with the aim of further improving levels of performance, whilst also preventing injury. The combination of feedback systems such as this, alongside more conventional forms of analysis has enabled a highly comprehensive review of an athlete's performance, in order to further promote their chances of success in a given sport.

However, the evolution of performance analysis is showing no sign of slowing down; and a combination of the fields of biomedicine, sports engineering, and nanotechnology are presenting themselves in the form of the 'nanobiosensor', which this chapter will critically discuss. This innovative technology has the potential to revolutionise sports, enabling real time biological data to be collated from athletes that can be electronically distributed and reviewed in real time. Therefore offering an additional layer of performance analysis in order to increase an athlete's potential for success, and increase their levels of safety whilst competing. However, before this

[14] Due to large sections of this chapter being published within the Journal of Science and Engineering Ethics in 2016 under the title - *Ethics, Nanobiosensors and Elite Sport: The Need for a New Governance Framework* - Regular and consistent references must consequently be made to this paper in accordance to the terms outlined in the *Creative Commons CC BY* license. This will be demonstrated via the following reference - (Evans et al. 2016).

discussion can take place, it is integral for this chapter to establish a knowledge foundation, which will begin by providing an overview of performance analysis, and a consideration of how performance related data is collected. This in turn will be followed by examples of feedback systems that are currently being utilised in elite sport for performance analysis purposes.

2. Performance Analysis - An Overview

The field of performance analysis is focused upon improving an athlete's performance levels through the analysis and interpretation of a wide variety of performance related data that has been collected, with the aim of offering real- and lapsed-time objective feedback to athletes (EIS 2019). This discipline has in turn allowed for coaches to adapt and evolve training regimes and tactics in order to improve an athlete's or team's chances of success whilst competing (EIS 2019). Objective feedback such as this has become vital to the coaching staff of any team or individual athlete, as research has shown that on average, only 30% of an elite athlete's performance is remembered, with performance analysis required to make up the other 70%; ensuring that athletes receive the best possible data and feedback in order to improve their performances (EIS 2019; Evans et al. 2016).

However, it must be made clear that performance analysis is not a homogenous phenomenon, with differences arising in relation to location, timing, and nature of the information (biological and psychological for example) (Evans et al. 2016). Consequently the collection of data for performance analysis purposes can either take place after an athlete performs (on the side of a track for example), or it can take place in a laboratory, which can offer a more controlled environment for the review and trialing of new ideas (Evans et.al 2016). Furthermore, the data collected for performance analysis purposes is done so through the use of advanced video performance software such as 'Dartfish' (n.d.), with the feedback then presented to athletes via a range of different methods, allowing for athletic advancements through enhanced analytics that encourage more critical performance feedback, and reflection between coaches and athletes (Evans et al. 2016).

3. Feedback Systems – Biosensors/Nanobiosensors Performance Analysis Systems

There are many different types of feedback system that are used for the purpose of performance analysis, such as the traditional methods of video analysis and motion analysis - both offering great benefits. However, these do also present a number of limitations, for example, in sports such as rowing which is highly technical, measuring skill level is both difficult (because of the distance between analyser and analysed) and time consuming via more traditional methods of camera feedback systems whereby the analyst physically watches the performances back in real time (Baca and Kornfield 2006). Yet it is clear that these limitations have been overcome as the field of performance analysis has evolved, and new technologies integrated. If we take a look at rowing, it is evident that the application of standard mobile electronic devices fitted directly to the boat enable precise and immediate data transfer regarding rowing technique (Baca and Kornfield 2006; Evans et.al 2016). The data is supported by land-based feedback systems allowing for the monitoring of factors that may affect an athlete's rowing technique. The purpose of these systems is to record horizontal and vertical reaction forces as well as standard pulling forces, which is then displayed to the rower during execution, so that continued adaptations can be made for optimum technical performance (Baca and Kornfield 2006). Therefore complimenting the more traditional methods of performance analysis, and thus offering comprehensive feedback to the athlete or team.

The sport of swimming has also greatly benefitted from improvements due to the implementation of performance analysis systems, clearly demonstrated by the British Olympic team who have integrated state of the art movement tracking and sensor systems to their training regimes (EPSRC 2012; Evans et al. 2016). This technology involves the use of multiple sensors to transmit athlete data wirelessly through the water to a computer, allowing for a swimmer to be tracked wirelessly, and data to be generated relating to an athlete’s movements (such as body position and acceleration). Coaches can subsequently offer immediate, detailed and objective feedback (EPSRC 2012). Prior to these sensors, the coaching team would have had to give feedback to swimmers through observational and video-based analysis post-training, which as mentioned earlier, can sometimes be problematic due to lack of memory precision and immediacy.

Yet despite the benefit over traditional observational methods, this form of feedback is still limited, addressing only the external movements of an athlete. Consequently, sports engineers have looked to other fields of research such as biomedicine and engineering to help solve the problem, and have emerged with the 'biosensor', enabling biological data capture through mobile devices. Biosensor offer athletes and coaches a revolution in sport analysis, as they provide the ability to gain biological data from athletes wirelessly and in real time, recording key information such as heart rate and respiration levels (Moskvitch 2012; Evans et al. 2016). This is highly beneficial, as it offers a more complete picture of an athlete's fitness and performance levels. It also generates a more personalised approach to training, enhancing performance levels, and predicating when an athlete may be at risk; reducing the chances of potential injury or worse. Consequently, devices such as this are now being considered as essential in evolving the practice of performance analysis as outlined by Moskvitch (2012):

> *Biosensors are a new frontier in sports – now we can get the data from performing athletes wirelessly, continuously and in real time," she says. "We can record things like acceleration and position, heart rate, respiration and fatigue, combine the measurements, and mash them up using sophisticated statistics and analytics, to get a complete picture of an athlete's fitness, and more insight into what his or her body metrics look like during performance. This provides a complete view of what factors influence the performance – and that has to do with what you'd eaten and how much you'd slept the night before. The data is then used to develop a more personalized approach to training, enhancing performance, as well as to predict what might put an athlete at risk, facilitating the very early diagnosis of, for instance, cardiac arrest.*

However, before going any further, it is essential to gain an understanding of what biosensors are. There are many definitions relating to biosensors, but there are two that are widely recognised. The first of which defines a biosensor as a chemical sensing device in which a biologically derived recognition entity is coupled to a transducer, allowing for the quantitative development of some 'complex biochemical parameter' (Higson et al. 1994; Frazer 1994, cited in Mohanty and Kougianos 2006 p.35; Evans et al. 2016). In contrast, the second defines a biosensor as 'an analytical device incorporating a deliberate and intimate combination of a specific biological element and physical element' (Higson et al. 1994; Frazer 1994, cited in Mohanty and Kougianos 2006, p.35; Evans et al. 2016). Biosensors therefore consist of two parts: a bioelement and a sensing element (Mohanty and Kougianos 2006). They comprise of a biorecongnition element that responds to a target compound that creates a biological response, which is then converted by the transducer to a detectable signal, measured via *inter alia* optically or acoustically (Touhami 2014). The use of biosensors can support an athlete's pursuit of excellence, as they can be applied to keep them in peak physical condition, ensuring high levels of endurance, speed and efficiency (Montgomery 2010). But to remain in this condition while training *in extremis* for extended periods is highly challenging. It is often said that good health ends where elite fitness begins. Precise, accurate and timely monitoring is therefore essential to athlete centered sport technology and sports medicine (Dijkstra et al. 2014).

An example of a biosensor used for sporting purposes is that of the Pulse Oximeter (Sheehan 2010; Evans et al. 2016). This is a handheld electronic device that is applied to measure the amount of oxygen in an athlete's blood. It works by clipping the device onto an athlete's index finger, which then radiates infrared light. The oxygenated and deoxygenated blood absorb at different levels enabling the accurate calculation of oxygen is the athlete's blood (Sheehan 2010). The ability to measure oxygen in the blood is essential since optimum lung function is vital to efficient metabolism and muscle function, particularly during high intensity exercise, where the muscles are working harder for longer periods of time (Montgomery 2010; Evans et al. 2016). The Pulse Oximeter is then used to monitor potential oxygen drops during situations such as these, enabling new training methods to improve stamina for example, in order to generate further performance gains (Evans et al. 2016).

Nevertheless, biosensors currently have limitations such as the (i) volume of biological data they are able to collect; (ii) practical functionality for elite athletes in terms of size and bodily restriction; and (iii) over-sensitivity that can sometimes lead to false data measurement. Consequently, sports and biomedical engineers have sought to overcome these deficiencies in the form of nanobiosensors. Such sensors can be defined as a biosensor consisting of nanomaterials and with the dimensions on the nanometer (1 nm = 10–9 m) (Nada et al. 2011, p.92; Evans et al 2016). The incredibly small size of nanobiosensors offers multiple advantages, as due to the large surface area to volume ratio; many of the nanomaterial atoms are located near their surface, resulting in improved transducing and signaling capabilities (Malik et al. 2013). This increases their ability to detect and provide more accurate data recording. Further, these devices can be fitted to a person without irritation, and placed either sub dermally or externally on the body for extended lengths of time. One of the main reasons for this is possibly due to the production of thin films made of nanomaterials, which are able to increase the detection of molecules such as enzymes and DNA, consequently allowing for real time monitoring, which is highly beneficial to elite athlete and their performance progression (SHL 2014; Evans et al. 2016).

4. An Example of Nanobiosensors Feedback Systems for Performance Analysis

As previously stated, nanobiosensors offer elite sport huge potential, but are still very much in their early research phase. However, examples of this technology are slowly emerging and being trialed in a number of fields, including sport. One such example is that of a non-invasive ‘nanotattoo’, which can be placed on an athlete's arm to monitor lactate levels in perspiration (Wenzhao J et al. 2013; Evans et al.2016). The monitoring of lactate is an essential indicator for assessing an athlete’s physical performance during training and competition, offering an ability to identify multiple sprint and speed endurance. Traditionally, lactate levels have been monitored through the use of lactate sensor strips that are used in combination with a handheld device, which is both inconvenient and intrusive during physical activity (Wenzhao J et al. 2013; Evans et al. 2016). By contrast, the non-invasive enzymatic temporary-transfer tattoo acts as a flexible sensor made through screen printing methods, which flexes to fit the body so that it is non-intrusive and resilient to cope with intensive exercises, due ‘to the presences of dispersed carbon fibres within the screen printed inks’ (Wenzhao J et al. 2013; Evans at al. 2016). Furthermore, it works to establish a more precise measure of an athlete's lactate levels; a very significant performance inhibitor, enabling biological data to be gained immediately, allowing for immediate interventions in training sessions to take place in order to improve performance.

It is clear that the application of recent bioengineering innovations via biosensors and potential future nanobiosensors are beginning to revolutionise the landscape of performance analysis. The development of advanced feedback systems utilising sensor and image processing facilitate instant data transfer to laptops and smart devices for analysis (Haake 2013). This has allowed for far more effective feedback systems to be developed, and increased levels of biological data to be gained in real time (Baca and Kornfeind 2006). Although the use of this technology may be considered pivotal to the development of performance analysis, it must be recognised that it also generates significant ethical debate in relation to its application to elite sport.

5. Ethical Benefits and Disbenefits of using Nanobiosensors for Performance Analysis

Having established that the potential use of nanobiosensors in elite sport is exceptionally promising, this chapter will now consider the potential benefits and disbenefits that this technology may generate for elite sport.

Table 3: The benefits and disbenefits of using nanobiosensors for performance analysis (Evans et al. 2016)

Benefits for the athlete	Benefits for the system	Disbenefits for the athlete	Disbenefits for the system
Increased Performance Data	**Improved Safety in Sport**	**Athlete Consent, Confidentiality and Data Ownership**	**Unfair Competition in Sport - 'Technology Doping'**
Increased Value for the Athlete	**Deterrence to Cheating**	**Deskilling of an Athlete**	**Facilitation of Corruption**

6. Benefits for the Athlete

6.1 Increased Performance Data

Previously, performance analysis has been limited due to biological data not being readily available for analysis. However, with the integration of biosensors and potential nanobiosensors in future, coaches and athletes are gaining a far greater understanding of how an athlete's body works. The future use of nanobiosensors in the form of wearable technology will be able to wirelessly track a number of bodily functions such as rates of dehydration, recovery, lactate levels and even wound healing (SHL 2014; Evans et al. 2016). This will move athletes and coaches away from reliance on physical metrics, and provide a more accurate picture of an athlete's biological function. Moreover, increasing the amount of data available for performance analysis, and allowing coaches and athletes to develop a far more bespoke approach to training, thus, creating greater potential for successful outcomes in competition (Saxon 2011; Evans et al.2016). The use of nanobiosensors also increases the speed and availability of data, which is transmitted in real time to coaches and athletes on their smart phones or tablets, enabling immediate interventions.

An increase in data such as this could be vital in the early detection of potential injury. This would be essential for an athlete, as long-term injury often has a negative impact on the careers of individuals, taking them away from the sport, and limiting their chances of potential success. Or in the case of team sports, we could see groups losing their place to another desperate for their chance. Therefore staying fit, healthy and injury free is essential to the continued success of an elite athlete. Furthermore, systems such as this could actually be life saving, especially if an athlete is suffering from an undetected heart condition, which could for example result in sudden cardiac arrest. This has become a particular concern amongst athletes, coaches and teams, and was highlighted by the distressing scene of Fabrice Muamba's cardiac arrest during a football match between Bolton Wanders and Tottenham Hotspur in 2012 (Feguson 2012). Fortunately Muamba survived due to the rapid response of the medical staff that were pitch side, however others have not been so lucky. Hence, if an athlete were wearing a nanobiosensor, then this device would be able to alert those on the sidelines of any potential cardiac risk, allowing for action to be taken before a permanent or life ending attack takes place. This technology would therefore not only aid an athlete in terms of improving their performance, but also their safety.

6.2 Increased Value for the Athlete

Player performance statistics have played an increasingly prevalent role in the renegotiations of contracts and salaries (Socolow 2015; Evans et al. 2016). As Marathe, Chief Strategy Officer of the San Francisco 49ers states, 'good data insights can make or break a player being hired or a coach being fired' (Brousell 2014; Evans et al. 2016). Nevertheless, at present this data is often limited to injury and basic health statistics collected by wearable devices (Socolow 2015). Consequently, such data only provides an idea of what an athlete's future performance may be, and therefore lacks accuracy.

Recent advancements in biosensors (and with confidence we may say in the near future, Nanobiosensors too) have brought significant enhancement in the levels of biological data including indicators of long-term health and future injury rates (Evans et al. 2016). The data can play positively into the hands of an athlete, as strong biometric data can work to increase the value of an athlete; not only to a team or organization, but also financially to the club or franchise (Socolow 2015; Evans et al. 2016). For example, in the future if a football player is regularly being identified by monitoring through the use of nanobiosensors as the most physiologically superior player in a squad, this is likely to increase their economic value. Other measures could include players that have the lowest levels of lactate production through games; the calmest under pressure with lower heart rates during critical times in the game such as penalties or vital free kicks; or often more importantly to clubs, the player with lower injury frequency (Evans et al. 2016). In doing so, nanobiosensor data readings are likely to be used to further justify improved contracts, team transfers or salaries of players, particularly when comparisons can be drawn directly between the biological data of any one player to another (Evans et al. 2016).

This could also be advantageous for clubs, as it will give managers the confidence to invest money in quality players without the fear of diminishing returns due to long-term injury, thereby reducing risk from the offset (Evans et al. 2016). Avoiding frequent injury of star players where possible could also contribute to increased performance outcomes on the pitch, as a side is likely to remain fitter for longer; an essential element for any team mounting a campaign in extended competitions such as UK football's Premier League, or the National Football League in the USA (Evans et al. 2016). This idea is already coming into play in some elite sports such as basketball, with the National Basketball Players Association citing many examples of data collected from biosensor/wearable technology being used in current contract negotiations, helping to determine the value of a given player (Socolow 2015).

7. Disbenefits for the Athlete

7.1 Deskilling of an Athlete

There are concerns that the use of engineering in sports more generally may deskill athletes, creating a greater reliance on the technology and generate negative connotations for both the athlete, and the sport more generally (James 2010; Magdalinksi, 2008; Miah, 2006; Evans et al. 2016). In a system where one values the general capacity of an athlete to self-monitor a range of capacities or performance dimensions, or to make autonomous decisions regarding how they are performing within a competition, it is clear this deskilling is undesirable (Evans et al. 2016). It has the ability to alter the way a sport is played or carried out, as it can change the training required to learn a new skill (Miah 2006; Evans et al. 2016). There are numerous examples of these types of technologies that blur this issue, such as depth finders in fishing to make it easier to locate fish, as well as U-groove golf clubs allowing for greater accuracy when taking a shot (Hardman 2001; Miah 2006; Evans at al. 2016). Yet both were banned from their representative sports, as it was felt that they undermined key skills constitutive of elite performance, leading to a devaluation of the challenge that was thought central to the activities (Miah 2006; Evans et al. 2016).

A similar concern arises over the use of nanobiosensors in the future to maintain an athlete's biological function. Self-monitoring is an important aspect of being an elite athlete; evidence can be shown in the ability to control one's diet, know one's limits, or find ways to adapt training approaches when extant training or performance strategies are sub-optimal (Evans et al 2016). It can be argued that the underlying competencies for these abilities are part of what separates the elite athlete from the merely good performer (Evans et al. 2016). Nevertheless, if sensors such as nanobiosensors provide the level and speed of precise data, which coaches interpret and base interventions upon, one may ask in addition whether the traditional skill set of the coach and athlete will be lost, or perhaps transformed? For example, when athletes are training, they require a skill level to work out when would be an ideal time to stop before they risk injuring themselves (Evans et al. 2016). The athlete wearing a nanobiosensor appears to render this competence redundant, as the device would inform the athlete as to when they need to stop, instead of them trusting in their own knowledge of their body (Evans et al. 2016). A further example could be diet, an area in which many athletes are skilled in knowing what exactly they need to eat and when to ensure their body continues to perform the way they want it to for successful outcomes (Evans et al. 2016). Yet if an athlete is wearing a nanobiosensor that can inform them of the nutrients they require, at the point of optimal need, it will remove the judgmental capacity an athlete requires when implementing and developing an effective dietary plan. Hence, the use of nanobiosensors could potentially devalue sport by reducing the skill required of an athlete to take part at elite levels, much like the U-groove golf clubs and depth finders mentioned earlier. Finally, some sports value autonomy more than others (Evans et al. 2016). Thus in tennis, coaching from the sidelines is forbidden by the rules. Once the player steps on the court it is he or her alone against their opponent. This is in stark contrast to, say, American Football where technology intervenes more readily and more frequently, diminishing player autonomy and enhancing system control (Evans et al. 2016). Whether enhancing system control over athletes is a good or bad thing for sports is a moot point to be considered on a case-by-case basis (Loland 2002; Evans et al. 2016).

As a consequence, the use of technological innovation has resulted in performance comparisons in many sports becoming less meaningful, as some argue that technology has enabled athletes to surpass records set by previous masters with relative ease, without having to develop the same level of skill (Evans et al. 2016). Some feel that this is not only disrespectful to these previous masters of a sport, but against continuity of sporting traditions (James 2010; Evans et al. 2016). This point is similarly discussed by Carr (2008; Evans et al. 2016) who argues that the role of sports engineering is to support the development on an athlete, *not* to remove the need to develop key skills to be successful at a sport which people expect from an elite athlete, 'as that would be inconsistent with the point or purpose of play'. Therefore, it is essential that nanobiosensors be used to support the athlete, not remove the level of skill required to be an elite athlete (Evans et al. 2016).

7.2 Athlete Consent, Confidentiality and Data Ownership

The current use of biosensors, and the future use of nanobiosensors for performance analysis raises serious concerns surrounding the gathering of biological data from an athlete (Evans et al. 2016). Despite the benefits nanobiosensors may bring to an athlete's performance in the future, the benefits of this technology must be carefully balanced against key issues such as privacy, security, consent, and data ownership (Meingast et al. 2006; Evans et al. 2016). This kind of data could be highly sensitive, and may be considered more private than statistical data currently being collated in sport[15]. This could in turn create highly complex issues for organising bodies, as the path to clear and controlled regulation of nanobiosensors in sport could prove problematic (Evans et al. 2016).

Consider the issue of consent in regards to nanobiosensors; as due to the complex nature of the technology and the knowledge gaps we have surrounding how nanoparticles alter human physiology, there is a concern over whether we possess sufficient understanding of the technology to allow for consent to be properly informed (Brewer and Gurel 2009; Evans et al. 2016). If you were to refer to the

[15] Not all authors agree on the conception of privacy this entails (Evans et al. 2016). For a contrast see McFee (2010).

field of medicine, before a doctor can carry out a procedure or treatment, they must seek patients' consent, to reasonably inform them of the details, risk and benefits associated with a given treatment before it can go ahead (Kegley 2004; NHS Choices n.d.; Evans et al. 2016). Where a reasonably complete set of details regarding the procedure cannot be provided, then the patient cannot be considered to have given *informed* consent (Kegley 2004; Evans et al. 2016). A similar train of thought can also be applied to use of nanobiosensors in elite sport. As although in vivo effects are not well understood at present, early studies have indicated that they may pose a risk to human health due to their unique size, allowing them to enter the body via channels such as the respiratory system, skin or mouth (NISOH 2009; Evans et al. 2016). Once in the body, they then have the potential to cross major bodily systems such as the blood brain barrier, posing serious health risks. Early evidence has indicated that nanomaterials have the potential to be toxic to human tissue and cell cultures (Madhwani 2013; Evans et al. 2016). As a consequence, this could mean that the health of athletes and players who wear nanobiosensors may be at risk (Evans et al. 2016). Further studies are required to discover the true extent of the potential risks associated with exposure to nanoparticles, which means until this knowledge gap is truly bridged, teams and organizations will not be able to provide a reasonable catalogue of the risks and benefits of using nanobiosensors, resulting in players and athletes both ethically and legally being unable to provide their informed consent (Evans et al. 2016).

Due to the potentially sensitive nature of information gathered by the use of nanobiosensors, one might presume that a player should be part of a consensual agreement for its wider use with third parties such as agents or physicians, as the data is collected and used in a manner that is not anonymous (Meingast et al. 2006; (Evans et al. 2016). Its use may be either beneficial or prejudicial to their interests. Ethical consideration of the use of data that may be prejudicial to the interests of individual athletes must be directed to the issues of ownership and storage. Who owns such data and consequent information flows? Do they belong to the athlete, or the club or organization they represent? According to present European law for example, ownership is dependent on who physically collects the information in the first instance (Evans et al. 2016). In our hypothetical case, it is likely to be the clubs or potential organisations that an athlete represents who would own the raw data and any analysis that takes place at a later date (Socolow 2015; Evans et al. 2016). This raises further questions of how this data would be stored once collected and in what form (Meingast et al. 2006; Evans et al. 2016). Should the raw data be collected and then stored locally or centrally? Which of these options offers better security in relation to the privacy needs of an athlete, to ensure that their information is not lost of stolen (Evans et al. 2016). Furthermore, who would be able to access this database, and thus access, alter or remove the athlete's private records? Would there be a system put in place for this, such as the one used in medicine where there are two categories for viewing records, those with read/write privileges (doctors and physiotherapists who may read and edit files) and those with read-only privileges (insurance providers for example) (Meingast et al. 2006; Evans et al. 2016). This is a key point that must be addressed before nanobiosensors are fully integrated into a given sport (Evans et al. 2016).

There are therefore serious concerns over the use of nanobiosensors in relation to privacy and confidentiality. In addition, the use of Wi-Fi nanobiosensors would alter the way in which athletes traditionally collect their biological data records, something not fully possible with current biosensors (although some are trialing this now), enabling instant data transfer (Evans et al. 2016). However, the potential use of WI-FI to transfer biological data of an athlete does raise concerns over security, as it exposes this data to greater levels of attack, for example via data hacking; leading to further concerns over privacy (Evans et al. 2016). For example, athletes' physiological vital signals are sensitive, and could identify that they may have an embarrassing disease or a career ending disease, so any leaking of this information could be deleterious to their interests (Kumar and Lee 2012; Evans et al. 2016). In previous years this was less of an issue, as paper-based records enabled easier restrictions to be placed on access to data (Evans et al. 2016). But once information is made available electronically, it may be easier for hackers to gain access and potentially increase the number of people who are able to view this sensitive information, which could be used against an athlete and potentially limit their career (Evans et al. 2016). In the context of elite sport, the recent Fancy Bears hacking of the WADA ADAMS database shows how athletes' medical records were posted online within minutes of being accessed by Russian hackers aggrieved at their country's expulsion form the Rio 2016 International Paralympic Games (Evans et al. 2016). Wireless sensor networks also bring considerable challenges to ensure the integrity of the data collected, as eavesdropping and skimming are a greater possibility when data is wirelessly transmitted (Meingast et al. 2006; Evans et al. 2016). This could make it a lot easier for opposing teams or athletes to be able to access another athlete's biological data in the hope of gaining an advantage over them (Evans et al. 2016). Therefore, it is vital that security and encryption services are well thought out when integrating this technology into elite sport, as if its not, it may generate social unrest amongst athletes, who may feel that their private and sometimes sensitive biological data could be at risk through hacking or misuse by private organizations, leading to potentially negative impacts on their careers (Ameen et al. 2010; Evans et. al 2016).

A further point regarding data security arises in the context of obligations to safeguard a player against third parties such as the broadcast media, or even video game creators, acquiring such information, or selling this on for profitable gain (Evans et al. 2016). Moreover, would clubs, teams and organizations be obliged to share the statistical analysis of data collected with the athlete or coaching team in question to enhance their own performance, or would there again be a cost implication involved? Each of these scenarios create a significant privacy and confidentiality issue, which athletes must be made aware of in relation to performance and training, but also key encounters such as contract negotiations (Evans et al. 2016). It is also important not to blur the line with athletes, and simply view them as guinea pigs for sports' biotechnological development (Camporesi and McNamee 2014; Evans et al. 2016).

Finally, the continual wearing of nanobiosensors raises concerns surrounding the blurring of the private/public distinction (Evans et al. 2016). This is highly relevant to occupational scenarios; when is an employee required to conform to their employer's demands? Of course, just about any clause for performance of duties may be written into a contract and consensually signed, yet if monitoring 24/7 is permitted, one wonders if the notion of a private life is rendered redundant. For example, Brian Buckle (a defensive lineman in the Canadian Football league) has referred to himself and his teammates as guinea pigs for new technologies, whose right to a private and family life (e.g. Article 8 of the European Charter for Human Rights) is compromised (Lindzon 2015; Evans et al. 2016).

8. Benefits for the Sporting System

8.1 Improved Safety in Sport

The development of sports engineering has been a significant driving force behind the development of safety in sport. As previously mentioned, Bjerkile (2009) considers the example of fencing, where sports engineering have made safety standards for clothes much more stringent (Evans et al. 2016). This has also proved beneficial to the public who decide to take up the sport, as it is viewed as a safer way of practicing, reducing the likelihood of a person receiving an injury (Evans et al. 2016).

The growth of nanobiosensors in the future may promote greater safety in sport (Saxon, 2011; Evans et al. 2016). The use of biosensors such as these can generate a safer playing field by helping to avoid injury, as their increased sensitivity can be used to check an athlete's vital health data, ensuring athletes conform to agreed risk standards (Evans et al. 2016). To demonstrate how biosensing technology such as nanobiosensors could be used to promote safety in sport, Saxon (2011) carried out a study of the changing heart rates of NFL players throughout a real game situation using heart rate patches gathering data from a tough scrimmage game that involved continuous changes in acceleration and significant physical contact (Evans et al. 2016). This form of monitoring was a breakthrough in the field, of which the purpose of the study was to gain baseline heart rate data for each player to establish what would be deemed 'normal heart rate', and 'abnormal heart rate' for a player in their position (Evans et al. 2016). Establishing data such as this proves beneficial for player welfare, allowing athletes to be monitored throughout a game in real time, and also enabling the coaching team to react in a prompt and effective manner when required (Evans et al. 2016). It may also prove highly beneficial in grueling pre-season preparations.

Therefore, the potential benefits that this new technology can bring to the sport are significant, not only through enhanced performance analysis, but also by providing vital statistics that could prevent long-term injury and increased safety for athlete welfare (Evans et al. 2016).

8.2 Deterrence to Cheating

Ever since competitive sport began at the time of the ancient Greeks, professional cheating has always been prevalent and has ever since become a scar on the sporting landscape (Møller 2015; Evans et al. 2016). There are many ways in which athletes and coaches can cheat, however in recent years doping has certainly been the most widely publicised (Evans et al. 2016).

At present, the main method of testing for doping is via urine or blood sample, which is sent to WADA accredited lab for testing (UKAD 2020). Athletes can be tested at anytime and in anyplace, both in and out of competition (UKAD 2020). Like all analytical techniques, this process has its flaws, as some new drugs have been specifically designed to evade this process. Moreover, the practice of micro doping has made detection exceptionally difficult, offering athletes huge gains that are virtually untraceable to current drug detection systems (McRae 2018). As a result, it has become far more difficult to detect, and therefore punish those athletes who are using prohibited substances and methods who illegitimately enhance performance (Evans et al. 2016).

The increased development and use of biosensors and nanobiosensors may act as a deterrent to cheating (Evans et al. 2016). Deviation from normal functioning for a particular athlete has been made more plausible by the Athletes Biological Passport, which takes measures over time (e.g. blood variables) where anti doping laboratories can look for peaks in biological markers and correlate them with athletes whereabouts data (MacGregor et al, 2012; Evans et al. 2016). Thus, inferring when athletes have gone on a "doping holiday", for example, in parts of the globe where they are difficult to track down by doping control officers (Evans et al. 2016).

Nanobiosensors could be used to further enhance this capability due to their potential for increased sensitivity and greater live-time monitoring (Evans et al. 2016). This could be highly beneficial to raising trust in sport, especially in sports such as athletics and cycling, where doping scandals have damaged its reputation and commercial value (Evans et al. 2016). The use of nanobiosensors could therefore be viewed by spectators as creating a fairer sport, generating a level playing field for the athletes, further reducing the chances for athletes and coaches to dope (Evans et al. 2016).

9. Disbenefits for the Sporting System

9.1 Unfair Competition in Sport – 'Technology Doping'?

The idea of technological doping is relatively new, referring to the advantages that may be brought to an athlete through using technology (PDD 2014; Evans et al. 2016). This has consequently raised the question of 'when does the competitive edge stop and unfair advantage begin?' (PDD 2014; Evans et al. 2016). After all, sport is a competitive business and if, for example, the British cycling team can build better bikes than other countries, should this not be allowed insofar as their scientists and engineers are working within extant regulations and parameters? This raises questions of relative fairness in contrast to equal opportunities to compete (Evans et al. 2016). Referred to as the 'fair opportunity principle', where a team although working within permissible parameters, gains such a significant advantage that it renders the competition unfair (Loland and Hoppeler, 2012; Evans et al. 2016). Most recently, the ruling body for European Football has attempted to diminish the effect that wealthy owners have had on winning teams by adding a new Financial Fair Play policy (UEFA 2015), which demands that clubs cannot continue to lose money while being underwritten by unlimited financial means over those clubs who stay within their commercial budget (Preuss, Haugen and Schubert 2014; Evans et al. 2016). In the USA, a draft system attempts to ensure some relative fairness in playing resources is provided as an alternative model.

The issue of fairness and use of technology in sport could also be raised in relation to nanobiosensors. I have noted above how this form of technology can offer athletes access to higher levels of biological data for performance analysis; something that could not be gained through traditional methods, consequently resulting in them being able to develop a much more bespoke approach to their training, and potentially gain new levels of success (Evans et al. 2016). Therefore it could reasonably be assumed that not all athletes will have access to these sensors due to high patent costs, resulting in a potentially unfair advantage to those who have them (Evans et al. 2016). For example, a marathon runner who is wearing a nanobiosensor in competition with their biological data being fed back to a coach who is watching, could potentially use this information to suggest ways of being more successful in the race (Evans et al. 2016). The coaching team may notice that the athlete is running low on glucose, and so could advise them to take a glucose providing drink as soon as possible to maintain consistent energy levels, which could be the difference between winning or losing (Evans et al. 2016). Thus, taking away the traditional skill a marathon runner requires to judge when they need to re-energise or not, and potentially providing an unfair competitive advantage (Evans et al. 2016).

There is also a concern that the increased integration of technologies such as nanobiosensors into sport using advancements may not be a test of an athlete’s abilities, but rather the strength of the technology systems (Loland, 2002; PDD 2014; Evans et al. 2016). This may lead to a technological arms race, where teams with the best resources will always have an advantage over others; a fear evident within Formula 1 motor racing at present, whereby the differences between the drivers are actually minimal, but every year the team with the most advanced technology wins. Hence, it is important to monitor the application of technology in sport to ensure that competitions remain fair for all athletes involved (Evans et al. 2016).

9.2 Facilitation of Corruption

If doping is the biggest threat to the integrity of sport, then match fixing or event manipulation must be a close second (McNamee 2014; Evans et al. 2016). The use of nanobiosensors for performance management brings many potential benefits, as noted earlier, yet their use within elite sport also has the potential to increase corruption in sport (Evans et al. 2016). Enabling real-time transfer of an athlete or team's biological data gained through future WI-FI enabled nanobiosensors might expose teams and athletes to data hacking, with key information being stolen or leaked deliberately to the opposition. This would give a new application to the saying 'stealing another coaches playbook' (Socolow 2015; Evans et al. 2016). For example, in rugby, a team's biological data could be hacked and shared with the opposition, allowing them to adapt their tactics in the hope of improving success rates (Evans et al. 2016). They may for instance discover that a key player runs low on glucose levels at certain points in the game, suffers from fatigue, or has a recurrent injury – and can therefore adapt their team play accordingly to target such player weaknesses, in the hope of swaying the result in their favour (Evans et al. 2016). Increasing the opportunity to improperly manipulate game outcomes or "match-fix" by stealing biological data is a domain that lacks a regulatory body[16] (Evans et al. 2016). It is questionable whether sports' existing regulatory frameworks could respond to this phenomenon, or whether criminal prosecutions in relation to data law would have to be pursued (Evans et al. 2016).

In addition, there are a number of labour concerns over the use of nanobiosensors, raising the potential for corruption to take place at a system level. As referred to earlier, athletes could potentially use the statistical data from the nanobiosensor performance analysis for positive reasons, such as strengthening their contractual situation with excellent biological data, or demonstrating a positive investment for a club or organization, though it is equally possible to have a negative effect on the

[16] The potential for hacking of key data is already a reality within elite sport, as demonstrated in 2013, when Liverpool football club were accused of hacking Manchester City's online scouting system known as *Scout7* (Ziegler and Dickinson 2019). The information gained was argued to have given Liverpool insight into Manchester City's players and tactical systems, offering them a competitive advantage (Ziegler and Dickinson 2019). Despite this, Liverpool and those involved admit no wrongdoing, and have rejected the allegations made against them; however the club did pay Manchester City a £1 million settlement (Ziegler and Dickinson 2019).

athletes themselves (Evans et al. 2016). For example, if a football player's data showed poor biological trends, this could work against them when signing for a new club or renegotiating contracts (Evans et al. 2016) .If a trend emerges that a specific player becomes fatigued during most games at around the 50-minute mark due to lactate build up, then this could actually reduce their value, as clubs could argue that they can get another player who has better biological endurance data, and in doing such, forcing a player into a diminished economic contract or cessation of employment (Evans et al. 2016). Furthermore, if a player is looking to move clubs, this information could be used against them, as no matter how well they perform on the pitch, their predisposition for early onset fatigue could deter a club from employing them (Evans et al. 2016). Information such as this could simply exacerbate periods of poor performance, which may not last indefinitely, but could affect their economic value. It could also add a lot of stress to an individual, as if they know that their biological performance data could be used against them in this way, it could also result in detrimental performance outcomes in matches, and more broadly in an athlete's career (Evans et al. 2016). Moreover, clubs could use this information to blackmail key players into staying at a club, as they could threaten to release potentially damaging information such as future injury to other clubs, which could make a player less attractive (Evans et al. 2016). Evidently, despite the potential positives nanobiosensors could bring to an athlete financially, it could also impact on them negatively, and have a detrimental effect on their financial situation as well as future employment (Evans et al. 2016).

10. Conclusion

Performance analysis is an essential training and competitive tool for any elite athlete, ensuring that they continue to attain essential marginal gains via reflective feedback practices (EIS n.d.). It is also a continually evolving practice, incorporating fields such as sports engineering and biomedical research to ensure that athletes receive cutting edge technology to allow for greater levels of analysis and feedback (TPD n.d.). This has clearly been shown through the integration of biosensors into sporting performance analysis, allowing biological data to be gained for new levels of feedback on an athlete's performance in both training and competition (Moskvitch 2012). This integration has already started to provide significant benefits to athletes in the sporting world, and the future development of nanobiosensors is only likely to further enhance this; allowing athletes to reach new levels of success. Nevertheless, before nanobiosensors become an everyday tool of sporting performance analysis and enhancement, considerations of their disbenefits - in terms of data access, ownership, confidentiality, privacy, and also athlete welfare, must be taken into account by sporting regulatory bodies to consider the impact they may have not only on the athlete, but also the sporting system as a whole.

In the next chapter, the final case study will be considered, which relates to the third–party use of nanotechnology in elite sport for horse race betting. This will look to review this potential technological opportunity, and consider the ethical benefits/disbenefits it may generate for the sport of horse racing.

Chapter 7 - Case Study Three: The Application of Nanotechnology for Sports Betting

1. Introduction

It is likely that elite sport and betting practices have been bedfellows, as long as sporting practices have existed[17]. Though analytically distinct, they have grown organically to the point where some sports or leagues only seem to include betting sponsors, whilst horse racing specifically seems to have almost been developed in order to provide a platform for betting. Sports betting is a thriving industry with a long history of highly successful and visible global financial links with major sports. Consequently, there are now more than 8,000 operators offering sports bets all over the world, generating vital revenue streams and drawing greater numbers of spectators to live sporting events (ICSS 2014). Horse racing has benefited significantly from its relationship with betting, extracting substantial profits from betting markets, and using it to boost its profile as an International sport across the world (Forrest 2006). Yet despite this, it has started in recent years to witness a pattern of decline in many countries, which has subsequently inhibited its betting revenues (Gibbs 2015; Hawkins n.d.). There are a number of reasons for this, such as the increased popularity of other sports such as football for example, which has attracted large investment from betting companies. Whereas horse racing's reliance on more 'traditional forms' of betting such as on track bookmakers/betting shops, along with existing concerns relating to animal welfare have left it lagging behind in comparison (Liebman 2010; Wood 2016; Christiansen 2010). These factors have presented challenges to the sport, and have consequently impacted its commercial foundations.

In response, the horse racing industry has endeavored to rejuvenate its image, in an attempt to appeal to new markets and attract a new generation of gamblers, via the engagement of new betting modes and web-based applications. This is evident

[17] A large section of this chapter is awaiting publication with the *Journal Sports, Ethics and Philosophy* - Doi: 10.1080/17511321.2020.1727946. Once published, a specific reference to this paper will be added to this chapter.

through the use of new technologies within the sport such as GPS sensors and Wi-Fi active racetracks; boosting the sports' online profile, and further promoting more immersive and interesting forms of betting (TPD 2013).

Despite such recent innovations within horse racing, new opportunities exist in order to push the boundaries of technology to innovate betting practices within the sport further. One way in which this could be achieved is via the application of biosensors and future potential nanobiosensors; this biotechnology could be used to collect biological data, opening potential benefits such as new betting forms, improved animal welfare, and greater levels of spectator immersion which could result in improved betting revenues (Evans et al. 2016). However, despite these potential benefits, a number of disbenefits, such as increased opportunities for corruption, issues concerning technological determinism, and concerns in relation to the use/fairness of the biological data collected also arise.

2. A Brief Overview of Sports Betting

Sports betting has a long history, with examples dating back at least as far as the Roman Empire, where bets were placed on circus events and chariot races (Moody 2013). Ever since, sports betting has continued to evolve, becoming more professional in the 19th Century; developing into an effective means of generating profit especially from horse races, consequently leading to some of the first bookmakers operating in England (Kyrylenko 2017). Sports betting continued to develop into the second half of the 20th Century, where bookmakers began to take bets on all types of sports, such as football; further helping to drive revenue streams for the industry (Kyrylenko 2017).

One of the most significant factors for the growth of sports betting may be a result of the emergence of the Internet, altering the way in which bets were distributed, as well as allowing for an unprecedented expansion of the industry (ICSS 2014). The Internet's use for sports betting has therefore been transformative, acting as an essential technological foundation layer for new betting practices/technologies to be built on, such as online bookmakers, betting exchange, and GPS sensors (Kyrylenko

2017; Betfair 2018). Both of which have offered new betting opportunities for the bookmaker and player, and hence, allowing the industry to generate new levels of profit from almost all competitive sports (Kyrylenko 2017). Mostly generated through football (494.44 million) horse racing (315.56 million) and tennis (61.6 million) (Wood 2016). As a consequence, the global sporting betting market is now a lucrative business, with figures suggesting that it was worth $76.1 billion dollars in 2013, $104.31 billion dollars in 2017, and expected to reach $155.49 dollars in 2024 (Zion 2018).

It is therefore clear that the sports betting industry is an established, and financially successful industry. Moreover, as shown, it has been a relevant element of human society throughout our history in one form or another. But what drives this industry? Why has it become such a success within human society? When one considers such questions, its success would seem illogical. The sports betting industry wants people to place bets, spending their hard-earned money to be bet on a given sport, where outcomes are relatively unknowable (unless it is fixed) in the hope of winning financial return. This on the surface would appear to be an act of madness; why would anyone partake in such an incredibly risky act, especially when the chances of financial loss are so high? It would appear to simply come down to luck as to whether one wins or loses. However this element of luck is exactly what drives the sports betting industry, as those who bet on sport (or anything else for that matter) are often doing so for the thrill of it; pitting their best and informed judgments against the system in the hope of winning and beating the system. This is what makes the act of betting on the whole exciting; it taps into our base pleasures and provides a thrill that many other activities are unable to match. In a survey of 5,500 gamblers conducted by Nottingham Trent University, it was clearly identified that one of the key motivations for gambling was the hope of 'winning big money', but this was incredibly closely followed by other factors such as fun and excitement (Baraniuk 2016). Consequently, even when a gambler is losing and the risks are high, their body is still producing adrenalin and endorphins, which keeps them on the edge, and provides them with a buzz - making gambling so addictive (Griffiths n.d., cited in Baraniuk 2016, para. 8). Consequently gamblers are not just hoping to win, they are buying entertainment. This point is further supported by a study conducted in 2009 by the University of Stanford in California (cited in Baraniuk 2016, para.10), whose findings revealed the following:

> *...................around 92% of people had "loss thresholds" below which they would not go. However, the fact that they lost money overall after visiting a casino, for example, did not necessarily impact their overall enjoyment of the experience.*

The desire to bet therefore goes beyond simply wishing to win, with those who do gamble regularly willing to sacrifice their potential personal and financial security in order to access the excitement that betting can offer. In some cases this is the very reason as to why many actually watch games within sport; for example - it's unlikely that someone would get up at 10.00am on a Sunday to watch an NFL team they do not follow unless they either have a passion for the game as whole, or have placed a wager on the match (Stewart 2014). Sports betting is therefore a challenge, and that is what makes it exciting and addicting as part of the wider contest (Stewart 2014).

Sports betting companies have tapped into this desire for excitement, and have been exploiting modern technology in order to promote the accessibility and immersive nature of the domain. This is clearly demonstrated by the emergence of sports betting apps, along with the wide variety of bets that are now possible in relation to any given sport. It is also clear that technology is altering our betting habits, for example allowing gamblers to bet from their own homes, meaning they no longer have to attend live events or betting shops to do this, which can promote negative stigmas for some (Christiansen 2010). Technology is increasingly playing a pivotal role in the development of sports betting, and with new and innovative technologies emerging such as that of nanobiosensors, sports betting is only likely to evolve further.

3. A Case Example of Sports Betting – Horse Racing

The beginnings of horse racing can be traced back to early Central Asia and the Mediterranean, where major events such as the first Olympics in Greece included competitive equestrian events (Croupier 2016). It was not, however, until around 1880 when formal annual races began, especially in the UK, with professional jockeys competing against one another (Huggins 2000). This period, of course, is consistent with what is called the birth of modern sport in Victorian Britain

(McIntosh 1979). Since then, betting on horses has flourished, with prize money available for those who won, which attracted people from all over the country to attend (Huggins 2000). This consequently had a domino effect across the UK, leading to the creation of racecourses all over England, whilst generating public demand for more betting; further generating an increase in commercial practices such as entry fees and media coverage (Huggins 2000). This led to the emergence of entrepreneurs offering odds (i.e. the emergence of the phrase "bookmaker" where "book" was a pseudonym for the gambling odds) on races from the side of the track, which put betting at the very heart of the sport, supporting its expansion across the world (ICSS 2014). It has become particularly prevalent and profitable in Asia, which itself is correlated with practices of illegal and irregular betting (The Economist 2012; Porteous 2016). In addition, horse racing has also been successful in the UK, and has embedded itself within British Culture with 59 racecourses across the country, and a worth of £1.1 billion to the UK economy (Croupier 2016).

Despite global successes, some institutions of horse racing that orbit and sustain the practice, particularly in countries such as the UK, Australia and America[18], appear to be entering a period of financial stagnation (Hawkins 2014). For example in the UK, despite large attendance figures for major festivals within the sport such as Cheltenham, average attendances at racetracks have fallen by 7.8% since 2015; additionally attendances at other jump meetings have been lowered further, down by 25.3% in 2018 compared to 2002 (Ingle 2019; Baxter 2018). Field sizes have dropped, due to this, with new owners being reluctant to enter into races, resulting in a fall in overall prize money (Ingle 2019). This has in turn placed additional stress on betting companies, as in the eighties, horse racing accounted for around 85% of betting revenues, compared with less than a third today[19] (Allen 2018). Consequently Ladbrokes has stated that its in-store betting on horse racing is becoming unsustainable, and William Hill additionally declaring that turnover in relation to

[18] As referred to earlier, in some countries this pattern of decline is yet to be seen. An example is Hong Kong, where horse racing is thriving (Economist 2012). But this is mostly due to monopoly the Hong Kong Jockey Club has over betting in the country, as it's the central regulator for all betting practices, thereby promoting horse racing as the main focus for sports betting in relation to other sports (Hawkins 2014; Sportsbetting n.d.).

[19] Some within the industry argue that in more recent year's horse racing has seen a slight (although highly debated) revival. As the UK Gambling Commission noted that in March 2017, revenues were up 9% on the back of a 10.9% rise in turnover, and it still remains the second largest betting sport in the period (Allen 2018, para.5).

Horse Race betting is in significant decline (Thomas 2014; Allen 2018). This of course has had an impact on the overall betting income generated by the sport (Ingle 2019).

There are a number of causes for horse racing's recent decline as a betting sport, one of which is due to the fall in the number of horses being trained for races, with more than a 7 percent decline since 2010 due to a lack of money from failing spectatorship and betting revenues (Gibbs 2015; Ingle 2019; Baxter 2018). Its epithet, the "sport of kings" is well earned, given the cost of maintaining and training a race horse is an expensive endeavor, available to the very few. The average cost for a race horse is approximately £22,696 ($30,000) per year (Murray 2017). A vicious circle of decline may reasonably be envisaged; reduced revenues are likely to result in less horses being bought and trained, diminishing the pool of entrants into competitions. A reduction of races would ensue, creating downward pressures on race cards (number of races per day) and total event numbers.

A further issue here is that horse racing has not responded sufficiently swiftly to technological advancements in betting, and has in the past been opposed to wagering away from the track, especially in the 1970s and 1980s (Christiansen 2010; Ingle 2019). This fails to recognise that people often want to bet in places that are convenient to them, and has resulted in it falling behind sports such as football who have harnessed the transformative nature of the Internet in order to establish Online betting platforms; moving betting away from its traditional live-at-venue base (Christiansen 2010). Hence, this has resulted in spectators turning away from the sport, opting to embrace new forms of immersive betting systems offered in other domains such as football, moreover, attracting a younger demographic of gamblers to the sport by generating new levels of immersion (Viuker 2015). A prime example of this is Celtic football club in Scotland, who have understood the role the Internet can play in the promotion of sports betting and have therefore utilised it further by installing a powerful Wi-Fi service into their stadium (MacLeod 2014; Maytom 2014). This brought the convenience and effectiveness of the Internet to a live event, allowing for new betting practices to be made possible in a live situation. For example, the application of Wi-Fi to the stadium allowed for the development and installation of an app which not only allows spectators to see replays and check stats, but also bet on live in-play odds due to its partnership with Unibet (MacLeod 2014; Maytom 2014). In turn, helping to draw new spectators and increase betting revenues for the sport.

A decline in interest in traditional sports driven by factors such as ever-decreasing media coverage has also raised issues within horse racing, working to lower its profile in comparison to other sports such as football (Liebman 2010). As a consequence, spectator numbers have fallen, with people only turning out in numbers for the major events, for example the Triple Crown, with very little interest now being shown to everyday races that occur at racetracks, which are essential in helping to fund the sport and drive betting revenues (Liebman 2010).

The horse racing industry in the UK is attempting to stall this decline in a number of ways; in association with betting companies, horse racing institutions have begun to consider ways in which betting within the sport can be "reinvented" pursuant to the aim of attracting a new generation of gamblers to help boost revenues. To achieve this, horse racing is mainly turning to technological innovations and Internet connected devices/mobile apps (made possible by the establishment of the Internet - acting a technological foundation layer for modern sports betting) to enhance the spectators' betting experience, and consequently its online betting profile. A prime example of this is the UK Jockey Club's modifications of key British racecourses such as Cheltenham and Ascot (similar to the early example of Celtic football club), which has been upgraded with a high-speed Wi-Fi network (XIRRUS 2014; Cisco 2007). This has also been supported by the Cheltenham Racecourse app[20], which provides spectators with additional features such as the ability to buy race tickets, see fixtures/race cards, and place bets, therefore simplifying the betting process on and off the track (HRA n.d.).

Cheltenham, home to the famous Gold Cup festival of jump racing, is not the only racecourse to modify its track in this manner - others such as Royal Ascot have also carried out similar upgrades. The result of which is helping the sport to encourage new ideas and revenue streams that were not possible before the integration of Wi-Fi to racetracks. For example, the company *Total Performance Data* have been working

[20] Cheltenham is one of the UK's most famous racetracks and home to the Gold Cup, first run in 1924, as the highpoint of the Cheltenham Festival.

with racing organisations and have employed custom built wireless heart rate monitors and GPS tracking technology to 25, 000 horses across 9 racetracks, which has provided new levels of statistical data such as lap times and speed for around 3,000 races (TPD n.d.; TPD 2013). This has consequently opened a new range of possibilities for all stakeholders within the sport, helping to generate a more immersive experience for those involved, as it offers owners and trainers performance data that can be accessed through the Wi-Fi network straight to mobile devices (e.g. video footage, heart rate data and sectional times) (TPD 2013). It also offers bookmakers new analytical data to generate increased numbers of bets for customers viewing the race (TPD n.d.).

Yet despite these developments, horse racing is still struggling to compete with other sports such as football, which has already carried out similar modifications. Horse racing must therefore look at alternative avenues to ensure it is ahead of the curve in relation to betting innovation and immersion, remaining competitive with other sports moving forward. Due to the increased integration of the Internet, especially at racetracks, this is clearly now possible, as shown with the recent integration of GPS sensors by TPD (n.d.). Thus, the foundations are in place in order to add additional layers of immersive betting practices and technologies to sport, in order to boost its betting profile. One potential way of doing this is to turn to ‘Biomedical engineering’ and sensors such as ‘biosensors’, and in the future, ‘nanobiosensors’.

4. Current and Future Applications of Nanobiosensors to Horse Racing

Biosensors already play a role in modern horse racing, but are predominately restricted to veterinary uses at present within the sport. An example of a biosensor used for this purpose is the pulse oximeter, which monitors an animal's oxygen saturation levels (dvm 2011). This biosensor is a handheld device, and works as follows:

> ….. the pulse oximeter is the measurement of the differential absorption between two different wavelengths of light based on the Lambert-Beer law (the empirical relationship that relates the absorption of light to the properties of the material through which the light is travelling). Oxyhemooglobin absorbs more light in the infrared spectrum (600 to 750nm). The Pulse Oximeter has two light emitting diodes (LED) of different wavelengths, one red and the other infrared. Typically the red LED has a wavelength of 660 nm and the infrared a

> wavelength of 940 nm. The LEDs are pulsed on and off hundreds of times per second and a photodetector collects the red and infrared light that passes through the tissue the Pulse Oximeter is placed on. A ratio of red to infrared light absorption is developed and applied to an internal algorithm in the Pulse Oximeters software. A number is then displayed on the readout (dvm 2011, Para.4).

Once the sensor produces the computerized read out, it will sound an alarm if the level of blood saturation falls below normal, alerting the vet to the potential of the horse becoming hypoxic, a vital signal to ensure that a horse is kept in the best of health (dvm 2011). This is incredibly important with regards to racehorses, as keeping them in peak condition is vital to ensuring that they not only physically compete in a race, but also ensures that they remain competitive when they do. These are also very expensive animals, so illnesses and potential deaths are highly costly to owners; therefore, methods used to reduce these chances are vital, especially in times where financial revenues are tight.

Nevertheless, biosensors as stated in the previous chapter have limitations, which researchers are now addressing with the potential forthcoming development of the nanobiosensor. Due to the production of thin films made from nanomaterials which are able to increase the detection of molecules such as enzymes and Deoxyribonucleic Acid (DNA), nanobiosensors could allow for real time monitoring, which would be highly beneficial to both owners and trainers in relation to performance progression (Malik et al. 2013). One particular example of this technology that has the potential to be applied to the field of horse racing is that of the non-invasive Nanotattoo, which is currently being developed for human use, but could also easily be transferred to that of animals, such as horses (Wenzhao J et al. 2013). This enzymatic temporary-transfer tattoo acts as a flexible sensor made through screen printing methods, which flexes to fit the body so that it is non-intrusive and resilient to cope with intensive exercises, due 'to the presences of dispersed carbon fibres within the screen printed inks' (Wenzhao J et al. 2013). This type of sensor could be a game changer particularly in a sport such as horse racing, as it would enable biological performance data to be accessed immediately, enabling rapid interventions in training sessions to either improve a horse and jockeys performance, or protect its health, ensuring it remains in peak physical condition. This could therefore be highly beneficial to owners and trainers of race horses alike; as a sensor such as this could be modified to fit a horse, allowing for biological data to be collected in real time, not only to benefit performance analysis and welfare, but also to potentially open up a new range of betting opportunities[21]. The biological data collated could also be used in order to provide new information in which to bet with, such as a horse's lactate levels of lap four, or its heart rate at the start of the race. Again, generating a new and immersive experience for the gambler within the sport, and allowing horse racing to offer a unique form of betting not found in other sports. This would work to potentially entice people back to the sport and continue to spend essential money on it. Therefore, although still in the early phases of research and development, examples of the implementation of a nanobisoensor such as this could potentially transform how biological data is collected and used in horse racing, and thus generating new betting revenues via increased data return and real time data retrieval.

5. Ethical Benefits and Disbenefits of using Nanobiosensors for Horse Race Betting

The following section will develop an ethical discussion of the benefits and disbenefits of this technology's application to horse race betting. These are listed in the table outlined below:

Table 4: The benefits and disbenefits of using nanobiosensors for horse race betting

Benefits of Using Nanobiosensors for Horse Race Betting	Disbenefits of Using Nanobiosensors for Horse Race Betting
New Forms of Betting	**Concerns Over Data Use/Interpretation and Fairness**
Increased Betting Immersion Through Technological Layering	**Increased Risk of Corruption and Addiction**
A Multipurpose Application	**Counter Productive to the Spirit of Betting**

[21] Along with the potential societal ethical harms that may be posed by the application of nanobisosensors for betting purposes - discussed later in the disbenefits section of this chapter.

6. The Benefits

6.1 *New Forms of Betting*

There are a number of bets available in horse racing, such as straight bets (where a wager is made on a single horse to finish a race in a certain position) and in-play/running bets (where a wager is made whilst the race is still being run) both offering the spectator a number of gambling options (Eng 2016; GC n.d.). Yet despite this, it is still argued that these are not immersive enough for the modern spectator and gambler. To increase spectator immersion, one could utilise biosensors and nanobiosensors, allowing for a horse's biological data to be collected throughout the race in real time, and simultaneously sent to a central hub, which in turn can be distributed to spectators via racecourse and betting apps. As a consequence, this could support the development of new forms of pre and mid race bets. Examples could include the extent to which a horse's pulse rate or sugar levels fluctuate throughout the race, or how much lactates a horse may build up during the final lap, or latter stages of a sprint.

The sensors could also be used to support a form of technology forecasting, allowing gamblers to better predict the outcomes of bets, and for betting companies to generate more accurate odds. This form of forecasting would be based on evidence collected from a range of sources, allowing for more accurate predictions to be generated, and thus, creating more informed betting choices (Firat et al. 2008). It is reasonable to predict that from a betting perspective, good forecasting could work to maximise gains and minimise losses (Firat et al. 2008). This, for example, could be vital in helping to increase the accuracy of in-running betting through exchanges. As a betting type, it requires judgments to be made in split seconds on many occasions, which is a lot of pressure and highly unpredictable - especially if the wager is high risk for example (OLBG n.d.). After all, the more information one has when making bets, the better the chances of success.

Although a valid argument, a challenge could be made here in relation to the use of this sensor technology in order to better predict bet outcomes. For a betting industry to effectively function, there must be losers, as this provides the financial security for the industry. This generates a potential tension between stakeholders, and it could be argued that such forecasting enables gamblers to maximise their gains, whilst minimising those of the industry. This surely would only result in the undermining of the sports betting industry? Although a valid point, it does not necessary imply that the use of this sensor technology and the betting industry are incompatible. Although this point does hold some merit, it can be challenged. Horse racing is an unpredictable sport, and no matter how much data a gambler may have, this does not guarantee that that they will be able to pick a winner. The history of betting has always shown this; where despite the evidence, the unexpected still happens in sport, making the placement of a successful bet an increasingly difficult challenge. Consequently, although nanobiosensors will offer greater data to place more informed bets, it will still require skill in order to interpret such data to determine the correct outcomes. Moreover, due to corruption that exists within the sport, this data could be irrelevant anyway, as for example - if a race is fixed, the selection of a race winner becomes almost impossible without insider knowledge. It is therefore clear that inaccuracy of human judgment and corruption can still result in misinformed bets, and chance still plays an intrinsic role in betting as a wider domain. An example of this can be seen via the recent victory of Tiger Roll during the 2019 Grand National race; a horse which only a year ago was deemed the smallest in the field, and given very little chance of success, due to its record of losing twice as many races as he had won in the past (Wood 2019). Another can be seen when considering the famous win of *Mine That Bird*, who entered the Kentucky Derby in 2009 with 50/1 odds (Dineen 2017). This result was unprecedented, with only one horse previously winning the Derby with longer odds; that being Donerail who was 91/1 before winning the Derby in 1913 (Dineen 2017).

6.2 *Increased Betting Immersion Through Technological Layering*

The drive to improve technology in horse racing has made significant leaps forward, especially with the development of Wi-Fi active stadiums. Nevertheless, the sport is looking to build on this further, identifying that technological immersion can help boost betting profits at home, at the track, and within betting shops. This is where biosensors and potential nanobiosensors could add another layer of immersion to the integration of new forms of betting technologies in horse racing. A prime example can be shown through the betting operator William Hill's research into Virtual Reality applications within betting in order to enhance the spectators' experience, by providing a jockey's view of the race (ISFPR 2015). The technology would be supported by the use of sensor technology such as GPS, providing displays with key analytical data such as lap times and speed (ISFPR 2015). It would also allow gamblers access to races all over the world, whether they are at the track, out and about, or at home (Davies 2015).

Despite the technology still being it its research and development stages, the application of biosensors and nanobiosensors, as stated earlier, could add an additional layer to technological innovation within sports betting. This data could be used to generate more informed betting choices, boost spectator numbers, and generate economic benefits for a sport in decline. As a consequence, the potential combination of these technologies could help to improve the betting experience within the sport, making it more exciting, and allowing gamblers to feel more a part of the action once they place their bets, instead of simply watching a screen for the results to be revealed. Consequently, likely correlating to greater numbers of bets being placed, and therefore improved betting revenues for the sport as a whole.

6.3 *A Multipurpose Application*

Although this paper focuses on the potential of nanobiosensors for betting within horse racing, it would seem like a missed opportunity not to offer some consideration in relation to additional benefits that a sensor such as this could offer horse racing, beyond that of sports betting. A prime example of this is the positive role that it could play in supporting animal welfare, demonstrating its multipurpose potential as a technology. There has been global recognition in recent years of the need for all sports to take ethical concerns more seriously; horse racing is no different, and concern over animal welfare is one of the reasons why some spectators have turned away from it in recent years (Liebman 2010; Barnett 2006; Torres and Chen 2012; Ingle 2019; Wahlquist 2019; Peter 2019). It is felt by many that the sport fails to adhere to the notion of animal welfare, and does not take into consideration a horse's physical and mental state, ensuring that they are protected from unnecessary suffering (Rollin 2011). Examples such as the English Grand National, one of the sport's most lucrative races emphasises this point, claiming the lives of around 48 horses since 2000 (Merrit 2017). One of the main reasons for this is due to the course structure itself; the design is extremely challenging, with forty horses battling each other for space over a 4-mile track of obstacles, jumps and uneven terrain at high speeds (Bekhechi 2016). Immense strain is therefore placed on the horses, often resulting in them collapsing from exhaustion or suffering serious injuries such as leg fractures, which can in turn result in the horse having to be put down on the course. This can be demonstrated by the death of the 10-year-old horse Willie Mullins in the 2019 Grand National after falling after the first fence, resulting in it being in clear and apparent pain, and consequently having to be put down (Ostlere 2019b). This problem is not limited to the English Grand National alone, with seven horses having died at the 2016 Cheltenham festival and two at Aintree in 2019 (Bekhechi 2016; Ostlere 2019b). Further, this issue is not confined solely to the UK; other countries such as America are facing similar concerns with frequent protests over the sport. According to U.S Department of Agriculture data, more than 57,000 horses were shipped from America to Mexico and Canada in 2019 for slaughter; either due to injury, retirement, or in the 'prevention of abandonment' (Peter 2019). This issue is also prevalent in South Korea, where at least 30% of racehorses imported from Australia in the last five years have been sent to slaughter (Wahlquist 2019, para.18).

Many have subsequently turned away from the sport, looking to bet on other sports void of animal welfare concern such as football. Nanobiosensors could be used in order to address these concerns, as they will be able to monitor a range of biological factors as discussed earlier; helping to pinpoint exactly when a horse's welfare may be at risk and from what. In addition, the reduced size of the sensors mean that they can be worn for longer periods of time, which can in turn allow for continuous monitoring of the horse's health outside of training and racing to further promote the animals' present and future welfare. One avenue available to the sport's regulatory bodies is to mandate the use of these sensors. This development would not incur high costs for owners, due to the potentially cheap production cost of nanobiosensors, and would have the effect of endorsing the priority of the horse's welfare over and above winning revenues (Nanowerk 2015). Subverting the sensor's core purpose, in this case betting, promotes a positive side effect in promoting animal welfare.

7. The Disbenefits

7.1 *Concerns Over Data Use/Interpretation, and Fairness*

Despite the many benefits that data collated through biosensors and nanobiosensors could offer the sport in the future, it also raises a number of concerns. The improper use of such technology could be highly detrimental to many of the stakeholders involved in horse racing.

The use of biological data also raises concerns for owners, as a successful racehorse involves significant financial investment. Data collected from the sensors could be vital to sporting success, allowing performances to be enhanced and optimising financial return. Yet the value of this data increases the likelihood of it potentially being stolen or leaked. This could offer opposing owners an insight into the strengths and weaknesses of another horse, therefore providing a potential advantage over the rest of the field. Opposition owners could seek to gain a performance advantage, and betting companies to fix bets; further promoting unregulated betting, which could result in a loss of revenue and prestige for the owner, and reputational loss for the industry. Moreover, there would also be concerns regarding data ownership, as the person who collects the data is often the one who is legally presumed to own it (Socolow 2015). Consequently, if the betting companies are the ones to produce these sensors and therefore collect the data, they could be within their rights to withhold this information from the owners, and even use this data for third party use against the owners wishes, again resulting in further reduced revenue (Socolow 2015). It could be argued that an issue such as this is largely irrelevant, as contracts would be put in place between each stakeholder in order to determine data ownership. Yet this is uncharted territory, making the process far more complex - as no precedent has been set in relation to data ownership here. There would need to be extensive discussions between stakeholders regarding this issue, as it is unlikely that an owner who has invested significant sums of money into a racehorse is likely to sign away such valuable data easily. This issue would therefore need to be resolved before any contracts can be drawn up; failure to do so could prove to be highly problematic.

Concerns can also be raised over the impact this data could have on trainers and breeders. Positive biological feedback and betting trends around a horse using this type of sensor technology could result in positive connotations for trainers and breeders, which would demonstrate effective training and development of that horse, and could bring with it increased status and subsequent commercial activity. Conversely, this viewpoint can also be reversed; if data reveals negative trends of betting on a horse's biology, and data feedback reveals signs of poor breeding choices, or, for example, demonstrates an increased heart rate before jumps that may indicate its anxiety, the reverse may occur. Given the importance of reputation to these breeders and trainers, and how perceptions of expertise fuel those reputations, the possibility of loss of betting on their horses could potentially be catastrophic.

Another variable to be considered are jockeys on whom nanobiosensor data could also have impact. Poor betting trends[22] on a horse could be traced back to the jockey and their physical status or psychological capabilities in handling their horse. Might for example, a horse's biological feedback demonstrates a failure in the jockey's ability to nurse their ride over a challenging fence? The best jockeys are those who are able to relate intuitively to their horse, identifying their strengths and weaknesses gained through riding experience and the data analysis they have carried out off the track with training teams (Beam 2009). This allows for better control over the horse, and the ability to keep calm, steering the horse out of trouble when needed, or pushing for speed before the finishing post (Beam 2009); all of which combine to promote the best possible race outcome. Whenever data for a jockey or horse calls their ability into question (such as their skill of interpreting a horse's biological data in order to get the best out of their horse within a given race[23]) there may be significant consequences for the jockey's livelihood, which could lead to their

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[22] The term 'betting trends' in this sense refers to the number of bets placed on a given horse to win a race. The poorer the trend, the less likely people think that a horse is going to win a race.

[23] An additional point that could be made here relates to the potential for such sensors to provide inaccurate or false data readings, providing a false indication of the strengths and weaknesses of a jockey. Again, this could be highly detrimental to a jockey career, as it could either undermine their levels of performance or over inflate it, both of which could negatively impact their further progression within the sport.

replacement in favour of another jockey who generates better biological data when riding the same horse. Moreover, it could be used negatively in contract negotiations, with poor betting trends potentially devaluing a jockey's worth and inhibiting their earning potential, something already witnessed in the National Basketball Association in the USA in the form of tracking technology (Socolow 2015).

In addition to the varying ways in which the data could be used and interpreted, this technology also raises concerns relating to fairness. For example, if a betting company receives the data first, which presumably it would in order to generate betting odds; then it could be argued that betting companies have inside knowledge as to how a horse may perform by receiving sensor data early. This may allow for bet odd manipulation to take place in the favour of the betting company, reducing the chances of a gambler making a successful bet outcome and in turn promoting a distrust of betting companies, which may discourage gamblers from placing further bets with them in the future.

There are also side effects that could impact sport beyond betting practices, which although not a central focus on this paper, are worthy of discussion. An interesting example of the potential impact biological data use could have can be demonstrated in relation to breeding practices. One use of the data collected from the sensors would be to refine current selective breeding programmes, in order to improve the quality of race horses. In order to obtain the perfect racehorse (fast, strong, and light), breeding practices have focused solely on developing muscle concentrations, which have resulted in many horses having light and brittle bones (Clark 2011b; Jenkins 2008). The consequence of this being that horses become more prone to fractures and breaks, which leads to further suffering for the animal. An example of such was seen in 2006, where the US Kentucky Derby winner, Narbaro, broke three bones in his hind legs due to weaknesses, and after a series of failed surgeries had to be euthanised (Clark 2011b). Yet many horses do not even make it this far, as many foals are often identified as not having the ideal racing properties, which either results in them being aborted or sent to a slaughterhouse in some countries (Barnett 2006; Torres and Chen 2012). The use of technologies such as biosensors and nanobiosensors could further exacerbate this issue, as due to their sensing capabilities, selective breeding programmes could become far more effective, allowing for only those horses that present superior biological attributes to make the cut.

Finally, a point raised earlier in this paper outlined how nanobiosensors could be used in order to benefit animal welfare; by acting as an early detection device in order to limit a horse's potential health risks. Although a valid point, it could conversely be argued that the application and use of these sensors could potentially be used to put greater strain on a horse. This is because nanobiosensors could be used to inform jockeys, trainers and owners of when a horse is running comfortably, or when it is pushing hard and reaching its physiological limits. This could prove problematic, as like any sport, horse racing is a results based industry; the better a horse is and the more it wins, the greater the fame and fortune for those stakeholders involved. It would therefore seem logical that stakeholders may encourage the animal to run to its physical limits more often, even if uncomfortable when doing so, which could result in a greater risk to a horse's welfare, particularly in relation to over exertion. Hence, the use of nanobiosensors could encourage jockeys, trainers and owners to take more risks when considering a horse's welfare; using the data gained from the sensor as almost an 'energy bar' much like in a computer game, enabling horses to be pushed harder for longer in order to promote their chances of success both in and out of competition[24]. This adds another dimension to the already challenging issue of animal welfare in the sport.

7.2 *Increased Risk of Corruption and Addiction*

Corruption and addiction are ethical issues deeply intertwined in sports betting. The European Gaming and Betting Association (n.d.) state that unregulated betting is far higher than the regulated market, particularly in Asia, where Interpol have determined the unregulated betting market is worth over $500 billion per annum, and worldwide figures looking closer to $1 trillion. There are many reasons for this

[24] A counter argument could also be generated toward this point, as although nanobiosensors could be used to negatively impact a horse's welfare, it is unlikely that owners and trainers would wish for this to happen. As previously outlined, horses are a significant financial investment, especially once they make it to racing level (Murrary 2017). Consequently, it may seem unlikely that such a sensor would be used to push a horse regularly to its physical limits and risk injuring it, with it being a significant investment to all stakeholders involved in its ownership and care.

problem, but technological progression has been cited as one of the prominent causes, allowing for greater levels of event manipulation (i.e. bet fixing) and addiction than ever before (EGBA n.d.).

The potential use of biosensors and future nanobiosensors may exacerbate such corruption, by promoting new opportunities for unregulated betting to take place, along with potential event manipulation (bet fixing) (EGBA n.d.). For example, the connection between the sensors and Wi-Fi network clearly has the potential to be hacked - also known as a 'man-in-the-middle' attack (Serrano and Dreiling 2012; Evans et al. 2016). This is when hackers create fake access points, enabling race data to be intercepted not only from the sensors, but also from betting apps; which could result in event manipulation (or bet fixing), or information being sold to opponents in order to allow for unregulated bets to take place (Serrano and Dreiling 2012; Evans et al. 2016). Furthermore, there is also the potential for owners, trainers and jockeys to influence the sensors with the aim of manipulating results themselves. For example, they could feed the horse a sugar cube capsule to spike glucose levels as a method of fixing in-running bets (Evans et al. 2016). Or they could replace the sensor with a rogue version that transmits data to corrupt sources, allowing opportunities to manipulate results before they get to the spectator. The use of such sensors could also generate new opportunities for blackmail and extortion, as for example, if people are able to learn of a potential breeding defect via a horse's biological data, it could in turn be used to blackmail breeders in order for them to maintain their reputations; resulting in significant damage to their livelihood. It is clear that the sensors are not in themselves unethical, but rather that they can be put to unethical uses in order to undermine the sports integrity in a number of ways.

In conjunction with concerns over corruption, the use of this technology could also further drive the addiction problem generated by sports betting[25]. At present it is estimated that there are 350,000 people alone with a betting addiction within the UK, with over £7 billion spent annually (ISFPR 2015). The worry for some, is that the increased use of technology and online betting via tablets and mobile apps have

[25] It additionally could be argued that in terms of addiction resulting from betting, the decline in Horse Race betting may be in the interest of a broader set of people, reducing the potential for societal harm driven by sports betting. Consequently, the application of nanobiosensors in order to boost betting revenues within the sport should arguably be rejected on such grounds.

helped to make it more accessible for people to gamble and remove betting stigmas, resulting in more people developing an addiction. Betting via traditional methods such as at the track or in-store meant that addiction was indeed still possible to take place, however, the human aspect of 'staffed' kiosks could certainly help safeguard more vulnerable members of the general public against this; in particular the young. It is feared that new emerging technologies without built in safety precautions are more open to overuse by those who may have addictive personalities and may not have the capability to effectively monitor their own use (ISFPR 2015). This could be a concern regarding the integration of nanobiosensors in order to place bets, as the data generated via these sensors would only work to generate a far more immersive betting experience; increasing the levels of interaction with the sport, and potentially offering a problem gambler false hope of improving their odds of winning. This would be for some (especially those with already existing gambling addictions) highly problematic and difficult to switch off from, and may encourage them to participate in betting activities to a greater level (ISFPR 2015). The deleterious effects on the gambler are obvious to foresee.

7.3. *Counter Productive to the Spirit of Betting*

A further concern relating to the potential integration of nanobiosensors to Horse Race betting relates to that of counter productiveness. The reason why many choose to bet, as stated earlier, is because it is an exciting and exhilarating practice, combining luck and informed judgment with the hope of beating the odds and winning big. Yet the integration of these sensors may actually be counter-productive, by promoting technological determinism, resulting in gambling becoming more formulaic, and potentially less exciting. The increased data offered, along with the effective use of algorithms could result in betting becoming more predictable. The consequences of this increased predictability are various and reliant on a number of factors concerning the access to, and integrity of the data as we have discussed. It may give rise to negative impacts on gamblers by deterring or diminishing their betting activity, since the enjoyment of traditional betting is a complex amalgam of factors including; luck; planning, accessing information; analysing form and its variability under different track conditions; and pitting one's knowledge and judgment against the odds to determine the eventual outcome or placings. Once a bet is placed there is still a range of experiences for the gambler; waiting nervously for the start; imagining the tactics and form of other horse-jockey combinations; experiencing the highs of a win and the lows of a loss, then using this very experience to place another, and going through the motions all over again.

Technology such as nanobiosensors could therefore detract from this experience; reducing the element of luck during a bet due to increasing the amount of data that could be made available to spectators – which in turn could vastly increase the odds of winning if the gambler is able to read the data to enable greater accuracy and control (MacKenzie and Wajcman 1999). This would therefore become counter productive to the purpose of betting and what makes it exciting; that of intuition and luck, further promoting a form of technological determinism, which removes the fun and excitement of betting with technological control (MacKenzie and Wajcman 1999).

8. Conclusion

Sports betting is an ever growing and lucrative industry, drawing on revenue streams from all over the world (Statista 2017). It is also a continually evolving industry, regularly having to alter and adapt to the changing nature of the spectator and gambler. This has resulted in the integration of new technologies and online betting platforms through mobile apps for example, ensuring that betting remains fresh and innovative. Many sports have benefited from this via increased spectator numbers and profit, as seen clearly in sports such as football (Maytom 2014). Yet this evolution has left other sports still reliant on more traditional forms of betting, which in the UK in particular has negatively impacted its betting revenue streams in recent years.

Horse racing has however started to modify its betting practices, via the integration of modern technologies such as Wi-Fi active stadiums and GPS trackers in order to make the betting experience far more immersive (TPD n.d.). This has already helped to draw more spectators and gamblers to the sport; but the sport could go further with the introduction of biosensors and future nanobiosensors to collect biological data. This could potentially bring additional benefits such as new forms of in running betting, greater spectator numbers, as well as working to combat animal welfare issues. All of which could potentially boost horse racing betting revenue streams. However, before the potential benefits of this technology can be exploited, the disbenefits such as data interpretation, corruption and fairness must be raised and discussed in an open manner to ensure this technology is integrated in a safe and ethical manner.

Now that normative evidence has been established in relation to the ethical benefits/disbenefits presented by the nanotechnological case studies considered in this work. The next chapter will consider a 'hybrid' applied ethical analysis of the findings, in order to determine how to best progress with this technology.

Chapter 8 - A Review of the Case Study Findings - Moving Forward

1. Introduction

In review, the previous three chapters of this work have ethically considered in a consequentialist manner the benefits/disbenefits of nanotechnology's application to elite sport. This took place via the discussion of three nanotechnological case studies. The first of which considered its application to an enabling technology, with specific reference to the road bike; the second considered its application to an embedded technology, with specific reference to the potential use of nanobiosensors to the field of performance analysis; and the third and final case study considered the potential third party application of nanobiosensors for sports betting, with specific reference to horse racing.

The ethical discussion and analysis of the case studies offered an informative insight into the potential impacts nanotechnology may have on elite sport, not only at present, but also looking ahead to the future. Furthermore, this technology demonstrated the potential to offer a number of benefits to elite sport, such as improved levels of performance, safety, rapid biological data collection and financial opportunity. Yet in contrast, it also presented elite sport with a number of challenges via disbenefits generating concerns raising issues of fairness/equality, data privacy/ownership, and increased levels of corruption. Hence, the current and potential future integration of nanotechnology to elite sport is a complex issue, and one that must be addressed before the widespread application and use of nanotechnology takes place; working to reduce the potential risks associated with this technology, and exploit its potential benefits in order to further evolve sport for the better.

Now that normative evidence has been established through a consequentialist analysis of the case studies, an applied ethical analysis can be conducted. As previously stated earlier in this work, in order to determine defensible ethical and regulatory requirements for nanotechnology's use within elite sport, both consequentialist and deontological concepts will be reflected upon in order to promote what is right and good in sport. This will allow for consideration to be made as to how best to progress with each of the nanotechnological case examples and determine the level of threat they pose to the ethical integrity and nature of elite sport. This will allow us to determine a regulatory approach in relation to each of the nanotechnological case studies, ranging from regulation, keeping the status quo, and banning. All of which could be plausibly justified when considering the findings of each of the ethical discussions in relation to the case studies. Therefore, it is essential that a further discussion be had in relation to this issue, in order to determine the most beneficial course of action for both the individual athlete and sport as a whole. This chapter will aim to tackle this, firstly by considering technology's complex relationship with elite sport by drawing key distinctions between cheating and technology doping. This in turn will allow for a classification of risk to be established in relation to the nanotechnological case examples, working to inform any potential future action in relation to this technology.

2. Drawing a Distinction Between Technology Doping and Cheating

Despite elite sport's many complexities, its nature remains simple, with the winner of a competition determined by an athlete's skill level, commitment and effort (Brown 2015). The modern elite athlete is meant to be an ambassador of sporting virtues, and their success the result of continued hard work and sacrifice in order to be recognised as the best in their given sport. However, as sport has become increasingly more competitive, its nature and integrity is continually being challenged. This has consequently resulted in an increase of athletes, teams and coaches adopting a philosophy of sport centered on the negative notion of 'winning at all costs' (Volkwein 1995). Which has in turn led to moralistic values classically promoted by sport; such as those of hard work, skill and fair play being increasingly undermined in favour of cutting corners and fast results in order to access the benefits that success in modern sports brings (Wijethissa 2016; Sarremejane 2015). A clear example of this can be seen when considering elite sport's recent problematic relationship with performance enhancing drugs, where athletes have been willing to put their own health and reputation at risk in order to take banned substances as a way of gaining an advantage over their competitors to increase their chances of winning. This arguably undermines the purpose and nature of sport, by creating an unfair competition and an immoral victory. Sadly, there are a vast number of cases that we can now turn to in order to demonstrate this epidemic within elite sport. One of the most prevalent was that of Lance Armstrong; one of the most decorated athletes of all time, who admitted to using performance-enhancing drugs in each of his Tour De France wins from 1999-2005 (Johnston 2017). This was driven by his 'win-at-all costs' attitude, which consequently unearthed a significant drug culture within the sport; tarnishing the image of professional cycling (Saraceno 2013). But in recent years elite sport has faced a new and emerging challenge to its nature and integrity beyond that of performance enhancing drugs; that being technology. Due to technological advancement within sport, athletes, coaches and teams have increasingly used it as platform to gain an edge over their competitors. In many cases this advancement has being perfectly legitimate, and even in some cases progressive for a given sport. However, in other instances it has provided the athlete with an unfair advantage that has not been earned, swaying a competition in their favour, and undermining the integrity of sport (Consentein 2016).

At this point, it is essential to make a clear distinction between technology doping and technology cheating, as it is often the case that such terms are used to refer to the same thing, but are in fact very different. Technology cheating is the deliberate and intentional breaking of the rules of a given sport via the use of technology in order to undermine the competition and increase one's chances of success. There are many examples of technology cheating within the sporting domain, such as in 2016 when the 19 year old Belgian cyclist Femke van den Driessche was found with a motor in her bike, powered by a Bluetooth switch found beneath tape on her handlebars (Shanes 2016; Weston 2016a; Ashok 2017). This device was discovered by magnetic resonance testing, and the rider was consequently found to have breached UCI (2017) regulations that state that an athlete must power themselves via the circular motion of pedaling whilst competing (committing 'technical fraud/cheating'). She was consequently banned for 6 years with the fine of CHF 20,000, and her previous results were cancelled out dating back to 11th October 2015 (Weston 2016a). Femke was seen to purposely undermine the integrity of the sport through the breaking of its rules in an attempt to gain an undeserved victory. Furthermore, her act was seen to alter the nature of the sport, whereby her physical prowess was no longer driving the bike forward, but that of a motor, which could suggest that she was in fact partaking in what may instead resemble a 'motor sport'. A further example of technology cheating may be evident when considering the case of the Soviet Pentathlete Boris Onishchenko, who was disqualified from the 1976 Olympics for using an epee in fencing that had a concealed button in its guard, which triggered a point whether he had placed a hit on his opponent or not (Burnton 2012). Therefore, much like Femke, his actions altered the nature and purpose of the competition and sport, transforming it into something that it is not in order to be successful. In each of the above cases, the athlete has clearly and deliberately broken the rules of their given sport in order to increase their chances of winning, therefore undermining its integrity and nature. These are clear examples of how technology can be used to cheat, as neither athlete was looking to use technology to assist their own efforts, but rather to gain advantages that had not been earned (Weston 2016b).

In contrast, technology doping is an attempt to enhance one's own performance, often generating an unfair competition through unearned performance gains [26] (Weston 2016a). Although this sounds similar to that of technology cheating, it is a much more complex issue. Unlike technology cheating, which is the deliberate use of technology that breaks the rules, technology doping is the use of innovative technologies that are used within the rules (or loopholes in the rules) of a given sport (Weston 2016a; PDD 2012). There are many examples of what could be considered technology doping in the history of sport, for example the Tyrell P34 cars' unique use of six wheels in the 1976 and 1977 Formula 1 races offered its driver an advantage through increased grip and better handling, proving to be highly successful in races (Reynolds 2016). This was not deemed as cheating, as the rules failed to dictate the number of wheels that a car should have, and was instead viewed by some as a prime example of a team working within the rules (or the loopholes within the rules) in order to use technology to gain a performance enhancement and advantage over their competitors. Although such actions did not break any existing rules, it did work to

[26] This offers a slight deviation from the 'classical' use of the term 'doping' within sport, which often refers to an athlete deliberately breaking the rules through using prohibited drugs in order to improve training and sporting results (UNESCO 2017).

undermine the spirit of the sport, resulting in a rule change in 1983, where four wheels became an absolute rule (Reynolds 2016). Consequently, although technology doping is not officially deemed a method of cheating, it still presents similar negative connotations. The use of loopholes to acquire performance gains is often viewed as an underhand method of gaining an edge over one's competitors. This in turn can generate an unfair technological 'arms race', increasing the gap between those who have access to it, and those who do not. Consequently technologies viewed as forms of doping often end up being banned, or effectively regulated in order to protect the nature and spirit of sport.

On the contrary, there are those who would argue that such innovative thinking should not be prohibited, particularly if it is within rules; as such actions promote sporting evolution, and prevent stagnation (James 2010). Athletes and teams are expected to improve upon their performances, and the application of sports engineering and embedded technologies are essential to ensuring such improvements in performance are made. This may be considered a valid point, as in most cases technological innovation is not seen as bad in itself, but actively working to improve elite sport - clearly seen when considering the emergence of Titanium clubs and dimpled balls in golf for example. Both of have supported golfers by improving their levels of performance yet are not considered as cheating or undermining the integrity of the sport (Weston 2016a). Further, some technologies have worked to improve the safety of sport without adding to performance, such as the HANS (Head and Neck Support) used in motorsport (Weston 2016a). Technology doping consequently generates a moral and ethical 'grey area' within sport, as although advancements in technology are essential for sporting progression (as discussed above), it must not come at the cost of the purpose and nature of the competition (James 2010). Subsequently an essential balance must then be drawn, in order to maintain the fine line between man and machine and ensure that athletic performances are not devalued in the eyes of those stakeholders found both in and out of the sport.

This therefore raises the question as to where the line exists between technologies that are considered as assistive technologies, and those that are considered forms of 'technology doping', blurring the rules of a sport and challenging its spirit. Fundamentally this distinction falls to sporting regulatory bodies to determine, but a decision such as this can be very challenging, especially when such bodies are required to simultaneously try and promote advancements within the sport to prevent stagnation, whilst also protecting its nature and integrity (Weston 2016b).

A potential way in which this could be resolved would be by deploying the technological regulation model used in parathletic sport. This was developed in order to draw a distinction between technologies that are seen as assistive, and those that are seen as forms of technical doping (Weston 2016b; WPA 2018). The IPC framework for this is as follows:

> *1. Safety - the equipment must be safe for competitors, officials, spectators and the environment.*
>
> *2. Fairness - the athlete must not receive an unfair advantage against the spirit of the event they are contesting.*
>
> *3. Universality - the equipment must be reasonably commercially available to all.*
>
> *4. Physical prowess - human performance is the critical endeavour not the impact of the technology and equipment* (Weston 2016b, para.9).

Consequently, in order for a technology to be considered assistive, and potentially key to a sports continued progression within parathletic sport, it must meet each of the set criteria in the above framework. Conversely if it fails to do this, then its integration could be challenged as a form of technology doping, posing a threat to the integrity of sport, and its integration and use should be reconsidered. Further, although currently used in the context of parathletic sport, have a universal nature. Therefore, this framework could be used to aid any sporting regulatory body in deciding whether a technological innovation is a necessary assistive technology, or one that seeks to undermine it in relation to technological doping.

3. Nanotechnology - Cheating, Technical Doping or Progress?

After considering the discussions above in relation to the case studies ethically analysed in this research, it would already be possible to rule out each of the nanotechnological examples as forms of technology cheating. This is because at present, each case study example does not breach any of the rules in relation to the sports they are being, or potentially will be applied to. This is mostly due to the lack of existing regulation, meaning that deeming it as form of cheating would be invalid. This leaves two potential options available; either the nanotechnological examples within the case studies are methods of assistive technologies supporting sporting progression, or they are means of technology doping, blurring sport lines and challenging the spirit of sport. In order to clarify which category each of the case studies fall into, the IPC framework outlined above will be deployed.

Before this, it is first essential to offer a justification as to why this framework has been selected. Firstly, athletes within para-sport are often dependent upon the use of equipment to assist not only their training procedures, but also their competitive outcomes (Weston 2016b). Consequently, due to this reliance on technology, the lines between what is considered an assistive technology, and a form of technology doping can easily be blurred. This can have a highly detrimental impact on para-sport by challenging the fairness of a given competition, and as a result undermining the integrity of a given competition. The regulations within para-sport must therefore confront this balance between technologies that are considered as assistive, and those considered as technology doping, hence the establishment of the IPC framework (WPA 2018; Weston 2016b). This offers a considered and effective approach for the study and monitoring of emerging technologies within para-sport; allowing for effective decisions to be made in relation to their potential regulation (WPA 2018; Weston 2016b). Despite this, it could be argued that this framework is not the only available model in determining the difference between whether a technology is deemed as assistive or technology doping. As mentioned previously in this body of work, other frameworks do exist such as those used in order to govern technologies in sports such as cycling, swimming and motor racing. Moreover, each regulatory framework used within each of these sports offers rigorous regulation in order to ensure that sport remains fair and equal. This can clearly be seen when considering the aforementioned UCI (2017) *Technical Regulation*. Yet despite this, I still argue that in reference to this body of work, the IPC (WPA 2018) framework offers one of best fit as it offers a universal nature and can therefore be applied in order to determine the role of a technology across a range of sports. This is essential when considering the case studies ethically discussed in this work, as they do not solely focus on a single sport. Consequently, deploying a framework such as the UCI (2017) *Technical Regulation* offers too narrower a focus, only addressing technology debates in direct relation to cycling for example. This would therefore not be appropriate when having to consider whether a nanobiosensor is an assistive technology or a form of technology doping, and where the IPC (WPA 2018) framework offers an apparent advantage. Para-sports are comprehensive/wide ranging, and therefore the framework deployed by the IPC (WPA 2018) requires it to be more generic in nature, addressing key values to sport as whole, rather than being specific to a singular sport. The universal nature of the framework allows for its integrated use across a range of elite sports and technology forms; hence why I argue that it offers a framework of best fit in order to determine whether the case study examples discussed in this work are forms of assistive technologies or forms of technological doping.

3.1 Case Study One

1. Safety

After considering the findings of case study one, it is clear that nanotechnology offers cycling a number of benefits in terms of safety. The application of graphene to cycle frames for example, is already working to correct a safety flaw that currently exists in relation to carbon fibre. Its improved levels of heat distribution is helping to prevent the bike from unexpectedly shattering, a current draw back for carbon fibre frames (R-TECH 2017; Levitch 2015; Murnane 2017). Furthermore, the additional application of graphene and carbon nanotubes to cycle tyres, such as those produced by Vittoria, are also providing improved levels of grip and reducing stopping distances; thereby improving levels of safety by working to reduce the chances of falls and crashes, particularly in wet conditions at high speeds (Gibbons 2016).

Yet despite these obvious safety benefits, there were safety concerns in relation to the production of such nanotechnological equipment. This is driven by the current issues surrounding the process of nanomanufacturing, potentially exposing production line workers to dangerous toxicants such as nano dust (NIOSH 2009). There are also environmental concerns in relation to this issue, as we are unsure of whether nanoparticles may interact with the environment, and the long-term impacts that this interaction could have (Zhang et al. 2016). However, it must be noted at this stage, especially in relation to environmental risks, that there exists debate over the potential impacts such particles could have. At present, research in relation to toxicology of nanoparticles mainly takes place in controlled laboratory studies involving stem cell cultures, with some arguing that unrealistically high dosages are being used in the process (NanoTrust 2012). The reason for this is that 'overdoses' are required to trigger a reaction, which can exaggerate results outcomes when creating unrealistic exposure scenarios (NanoTrust 2012). Yet despite these arguments, risks such as this cannot be ruled out, and the early warning signs are still present (Zhang et al. 2016). Therefore, although not a direct safety concern in relation to the athlete, spectators and officials alike, it could have an impact on the image of cycling if not addressed. Further, such safety concerns are still highly relevant in relation a consequentialist analysis, as it is still a valid potential outcome that may be generated by nanotechnology's application to cycling.

2. Fairness

Throughout discussions relating to nanotechnology's application to cycling, a number of issues relating to financial fair play and equality of access to new and emerging technologies were generated. This was in particular reference to initial high cost of 'nano' integrated race bikes, which could limit the number of cyclists in the first instance that are able to exploit this technology's potential (Sexty 2017). Thus, it is likely that the wealthier teams, such as those as Team Ineos (formerly Sky), may be able to gain access before others; generating the feeling amongst some spectators and stakeholders that wealthier teams may be able to 'buy success' by accessing the best and most up to date technology forms (Ostlere 2019a). This would promote dominance of the wealthier teams, generating an unequal playing field, and again undermining the spirit of the sport (Ostlere 2019a).

This could be seen as a valid argument, as in recent years a funding gap has increasingly emerged at the elite level due to financial constraints that have hampered the sport, for example the ever-decreasing commercial advertisement within the sport (Pender 2018). Consequently, opening the door for increased private ownership within cycling, which has in turn generated a boost in financial disparity between the teams in terms of funding. To exemplify this, teams such as Sky (now Team Ineos) were able to invest £31 million in 2016 into their team's development, whereas smaller teams were only able to work off an annual budget of £5 million (Pender 2018). Funding gaps such as this could be problematic when considering nanotechnology's application to elite sport, and hence must be monitored, with potential financial fair play policies considered and implemented in order to ensure fair competition.

Conversely, although a valid point, it would seem unlikely that in the modern era of elite sport, particularly within cycling, that an athlete would not have access to this technology. Despite the funding gaps that exist between teams and nations, the sport is still a multimillion-dollar business, with a substantial following across the world (Pender 2018). Consequently, elite level cyclists are well funded, and therefore if technology such as 'nano' bikes as discussed earlier were deemed essential to success in competition, teams and nations would endeavor to provide their athletes with access to this technology (Gibson 2012b). This is clearly evident when considering the GB Olympic cycling team that has seen an increase in funding from £26 million to £30.6 million, allowing for additional investment in technological advancement (Gibson 2012b). Moreover, technological investment such as this is not a significant drain on most team's financial resources, with riders and staff wages accounting for 80% of the expenditure (Pender 2018). Despite the disparity and some teams working from lower budgets, at the elite road racing team level, the average World Tour Team budget is still £15 million (Pender 2018). Access to new technologies is often therefore not a significant issue in relation to other factors such rider's wages.

At present, it is unlikely that a disbenefit such as this is likely to impact elite level cycling significantly, as more teams are finically stable enough to access this technology even in its initial costly production stages. Yet despite this, there are funding gaps that are increasing within the sport, especially with the increase of private ownership of teams. This must be monitored and taken seriously in order to prevent any further gaps widening, and harm being brought to the integrity of the competition.

3. *Universality*

As per UCI (2017) regulation, any cycling equipment used at the elite level must be available on the commercial market. This allows all athletes and spectators alike the opportunity to possess this technology, and take advantage of its potential benefits. Further, nanotechnological bikes and tyres for example are already available on the commercial market, although at a high cost (Sexty 2017). Therefore, at present there does not exist exclusivity issues in relation to this technology's use within elite cycling.

Despite this, like in any sport, there are likely to be sponsorship deals that limit some athlete's access to certain 'nano' bikes, which could potentially have universality implications; working to reduce the access a cyclist has to a potentially improved bike. Some companies may have superior designs and production techniques in relation to the application of this technology to race bikes, which could put other athletes as a disadvantage. Yet this is not likely to be a significant issue, due to the majority of manufactures at the elite level being highly skilled at bike design and construction, so the differences between each bike will be minimal. Again, it would be unfair to dismiss this technology as a form of technology doping on grounds of universality, as at present the rules dictate that the technology must be available to all.

4. *Physical Prowess*

After considering the ethical discussions in relation to case study one, it would be difficult to suggest that the application of nanotechnology alters the way in which the sport is conducted, shifting its focus from the efforts of the human to that of the technology. Despite the potential performance gains it presents the cyclist, in order to exploit potential gains such as this, the cyclist is still required to apply their physical efforts and skill level in competition. Therefore, unlike the application of a motor to a bike for example, which does remove the need for a cyclist to apply their physical efforts, nanotechnology's current application to cycling does not. This technology therefore plays a more supportive role in aiding levels of performance and safety for the athlete, but does not dictate their performance outcomes.

An additional argument against nanotechnology's application to elite sport is that it may make the sport easier for the cyclist. This is because the potential performance benefits offered by this technology could allow for less effort to be applied in order to be successful, which could be the difference between winning and losing. Due to the reduced weight of a 'nano' bike, less energy may be required to propel it; yet despite this point holding some validity, there are not significant differences between the weight of 'nano' bikes and its carbon fibre counterpart due to current weight restrictions imposed by the UCI (2017). Thus, the advantage gained would be considered minimal, and unlikely to facilitate an athlete dominating a race. This would therefore not be considered as technology doping, but does not rule out the potential for further micromanagement of races.

At present it would be difficult to argue that this technology completely undermines the physical prowess required by the athlete in order to be successful within the sport. Moreover, nanotechnology is likely to assist a rider in achieving new levels of performance in a competition; allowing them to push the boundaries of success within the sport, and ensuring cycling remains fresh and relevant in the eyes of the spectator - essential for its success and continuation (James 2010). This does however still raise questions in relation to the potential micromanaging of results, where the focus increasingly shifts from man to machine. Results are therefore unlikely to be perceived as an athlete's efforts, but rather the technology; which much be considered when continuing to integrate this technology.

3.2 Case Study Two

1. Safety

After considering the findings of the case studies, the potential use of nanobiosensors for the purpose of performance analysis does present a number of significant plausible safety benefits. The wide range of data collected via sensors such as this could be tracked and monitored in order to ensure that an athlete remains in peak physical condition, and reduces their potential for injury and ill health. For example, if this technology is able to identify when an athlete is over worked, or struggling, then action can be taken in order to reduce potential risk, further promoting their ongoing safety. The technology could be used to identify and detect at the earliest opportunity any injury risks or underlining health conditions that could be detrimental to an athlete's safety, enabling action to be taken to reduce risk. It is also worth considering the positive impact that this technology may have when eventually branching out of elite sport, and entering into the wider domain of the consumer market. Sensors such as these could be used to further promote and protect the health and safety of the public when conducting their own sporting activity (Hakke 2012).

Hence, the application of this technology would present a number of significant advantages for elite sport, and promote the safety of the athlete and spectator alike; rejecting their use on such grounds would seem unreasonable. However we cannot ignore a number of early warning signs identified in relation to its use via early risk analysis. The first relates to probable risks that nanobiosensors may pose in terms of toxicology, such as those in relation to manufacturing; in coherence with earlier discussion during case study one (NIOSH 2009). There are also concerns relating to toxicology and clinical safety via its use by the athletes themselves; where nanoneedles required in sensors such as this may become loose, and enter the body (NIOSH 2009; Evans et al. 2016). The second relates to the lack of regulation and clinical safety that exists in relation to nanobiosensors due to its current infancy within research and development[27] (Evans et al. 2016). This is a concern as there are a number of emerging nanosensors under development with the ability to measure an analyte *in vivo*, offering the potential for continuous biological monitoring (Ruckhs, T. et al. 2014). Regulatory procedure would therefore have to be established in order to guarantee clinical safety, data control/access and continuous monitoring; much like regulation already established for existing biosensors (biotricity 2017; WHO 2019). This ties into the third concern; that there is opportunity for misinterpretation (or deliberate misinterpretation and hacking) of biological data, which could result in actions being taken that could put an athlete's health, reputation, and career at risk. Hence, safety of an athlete's biological data must be taken into consideration, with

[27] A point further discussed and clarified with solutions in Chapter Ten.

adequate privacy policies implemented, and data security networks established. This is not commonplace within elite sport at present due to the fact that sensors such as this are yet to be integrated; however, it is clear that consideration must be taken prior to this movement to ensure athlete safety.

After review, although on the whole the use of nanobiosensors within elite sport can be viewed as positive, there are considerations that must be made in order to reduce the risks it presents. Concerns regarding privacy and confidentiality are clearly evident, and must also be respected when establishing a regulatory protocol.

2. Fairness

The issue of fairness in relation to the application and use of nanobiosensors for athletic use does raise a number of key questions. It is argued that the use of this technology could intensify concerns relating to fairness of access, allowing some athletes performance benefits over others. These arguments would imply that the technology undermines the spirit of the sport by offering athletes with access to this technology a performance advantage, whilst also reducing the requirement of self-management. Although both are valid arguments, again it is likely that athletes at the elite level will receive the funding in order to integrate this technology into their training programmes, in the same way as biosensors currently are. Furthermore, due to the commercial availability and cost effectiveness of existing biosensors, which nanobiosensors are likely to emulate, this technology would be affordable for athletes at the elite level (Prasad 2014; Garcia et al. 2016). This challenges the notion of probable unfair distribution of nanobiosensors within elite sport. With that said, there maybe an integration gap, where some athletes who are better funded could gain initial access to this technology before others, allowing them to take advantage of the benefits that nanobiosensors may bring in a shorter time period. We must therefore consider the implications that this interim period may bring when continuing to promote fairness within a given sport.

3. Universality

In order to determine the potential universality of this technology, it is worth considering the availability of existing biosensors. At present, biosensors are commercially available to purchase without restriction in the public domain; and consequently, have widespread use in elite support. They are furthermore highly cost effective and easily accessible within the public health sector (Prasad 2014; Garcia et al. 2016). Nanobiosensors are simply a smaller and more sensitive equivalent of this technology; and so, it is fair to predict that this may also follow suit after safety trials are conducted.

4. Physical Prowess

The role of nanobiosensors within an athlete's development would very much mirror that of current biosensors; to provide biological data in order for an athlete, coach and team to monitor and assess athletic development, and introduce bespoke training programmes. In turn, this will improve performance levels of an athlete both in and out of competition, ensuring that they remain in peak physical condition. Therefore, as implied by the nature of performance analysis, sensors such as this would play a supportive role to further an athlete's preparation. Further, the use of such sensors does not take away the need for an athlete to apply their physical prowess within competition, and earn the victory via their own efforts and skill in the heat of battle. As we know, no matter how physically well conditioned and prepared an athlete is, it does not imply that they were will be victorious in competition. Most athletes at the elite level are equally as well trained and conditioned, with results often determined by numerous other factors outside of conditioning. A clear example of this in sporting history can be examined when considering the infamous Busta Douglas versus Mike Tyson boxing match, where the far superior and conditioned Tyson was expected to win comfortably due to his considerable physicality and skill. Yet despite the odds, and in one of the biggest upsets in boxing history, Tyson was beaten - knocked out in the 10th round by Douglas, proving that physicality and conditional excellence is simply not enough on its own to dominate a competition (Mitchell 2010).

A further concern is that it may work to deskill an athlete, as it is expected that athletes at the elite level should be able to self-monitor, whereas this technology could possibly remove their requirement to do so. However, this argument could be challenged, as it could equally be argued that the collation and analysis of such in-depth data in order to produce improved performance outcomes is actually a form of reskilling, and that it takes knowledge and skill to turn biological data into performance results. Moreover, although the collation of data may be perceived a simplistic task, this does not imply that it will automatically result in improved levels of performance. The data collected must be interpreted effectively in order for an athlete to progress, and requires a range of inputs from coaches to the athletes themselves - this takes skill, effort and dedication, all of which are virtues that are in line with the spirit of any sport. Although this does still allow for the micromanaging of outcomes, as small improvements in relation to training regimes and diet can improve an athlete's chances of success in competition. Again, shifting the emphasis of the result away from the efforts of the athlete towards the technology. In addition, the use of such sensors much like nanotechnology's use within bikes, could assist an athlete in reaching new levels of performance within their given sport. This would again work to ensure that a sport remains interesting and relevant in the eyes of the modern spectator, with athletes continuing to surpass previous athletic achievements, as expected in the world of modern elite sport (James 2010).

Hence, the application of future nanobiosensors, and the current use of biosensors, does not deter from physical prowess required to be an elite athlete. However, it does raise questions in relation to the potential deskilling of an athlete in relation to their own physical management, and again the potential micromanagement outcomes that must be taken into consideration.

3.3 - Case Study Three

1. Safety

After considering the discussions in relation to case study one, it is clear that the application of nanobiosensors to betting practices generates a mixed bag of outcomes when considering safety. Firstly, it could be assumed that its application as a technology presents horse racing with a number of advantageous safety options, much in the same way as they do in relation to their potential athletic use/application. For example, the application of this technology for equine use would allow for vital biological signs to be monitored and analysed constantly, promoting a horse's ongoing safety. Therefore, when a horse appears to be under great strain during a race, or is at a health risk during a training programme, then sensors such as this could work to prevent this; identifying the risk early, and therefore increasing the animal's safety. Furthermore, the application of such sensors to the sport would be a significant addition to the current methods of protecting an animal's welfare before races, where trainers have to submit videos of horses, detailed medication records, and veterinary checks before key events, for example Cheltenham (Keogh 2019b). The sensors would be able to provide additional live biological data in relation to the horse throughout the race, ensuring that it can be removed when at risk to protect its welfare. This would be vital for the sport to deter loss of spectatorship; and promote ethical values, boosting betting revenue streams through increased betting. Sensors such as this could also be used to identify animal rights cases, such as the over whipping of horses; whereby the sensors would detect if a horse is in pain - resulting in a jockey being punished (Keogh 2019a). In contrast, the application of nanobisensors could be proven highly useful in the early detection of potentially damaging outbreaks, such as the recent equine flu, which resulted in a six-day shut down of British horse racing to prevent further spreading of the virus (Keogh 2019c). This had a negative impact on the sport, with a total of 174 racing stables being placed in lock down, with races cancelled, and the British Horse Racing Authority refusing to take any risks of the disease spreading (Keogh 2019c). It is fair to say that this has had a detrimental impact on the sport, resulting in a considerable loss in betting revenue. Nanobiosensors could be used to combat this issue, by promoting animal welfare and safety, working to bring people back to the sport.

The use of nanobiosensors for betting within horse racing does however raise a safety concern in relation to the spectators themselves, and could aid the already problematic issue of gambling. The use of this technology to generate a more immersive experience could contribute to greater levels of addiction, not only amongst exiting problem gamblers, but those new to the practice. This may intensify existing problematic social issues relating to betting, and so attention must be given to the issue. Lastly, the toxicology issues referred to in case study two must again be considered, as such sensors could present a health risk to the horse itself.

2. Fairness

When considering the arguments in relation to the fairness of applying nanobiosensors to horserace betting, a number of issues were presented. These resembled similar concerns to those seen in case study two, such as unequal access to this technology within the sport for performance analysis purposes. Yet again, in a similar line of argument to that presented in case study two, it is unlikely that the technology would not be available to key stakeholders such as trainers and jockeys. The ownership and maintenance of a racehorse is costly, and therefore owners are often wealthy or working within wealthy ownership syndicates (ROA 2019). It is likely that these owners would invest in the technology if it were proven to promote their horse's performance levels, increasing their chances of winning and protecting their high value asset from injury. Furthermore, the use of existing biosensors as veterinary aids within horse racing are prominent, as all owners have a vested interest in improving their horse's levels of performance and safety in order to keep them in peak physical condition, and increase their potential of winning. It would therefore seem likely that owners would continue to invest in sensors such as nanobiosensors if enhancements can be made to this essential monitoring role. The use of existing biosensors within horse racing has also yet to generate concerns over fairness within the sport due to their widespread commercial viability and cost effectiveness as outlined above (Prasad 2014; Garcia et al. 2016).

If it were deemed that nanobiosensors were to be utilised for betting purposes, it would be likely that all stakeholders would again have a vested interest. Stakeholders are likely to proliferate and encourage its use within the sport to access the benefits that the technology may generate in relation to betting; much in the same way as GPS sensors produced by TPD (2013). This would further work to spread the use of this technology within the sport, with betting companies even funding their production and use; additionally, working to promote fair and equal access, limiting the potential for the undermining of the sport's spirit and values.

A further argument in relation to fairness relates to the act of betting itself. The data generated from the nanobisensors could be used as a form of technological determinism. This would allow gamblers to better predict the outcomes of a given race, and work to undermine the spirit of betting, through the reduction of skill in order to be successful in the act. Although this point does hold some merit, it can be challenged; horse racing is an unpredictable sport, and no matter how much data a gambler may have, this does not guarantee that that they will be able to pick a winner. The history of betting has always shown this, where despite the evidence the unexpected still happens in sport, making the placement of a successful bet an increasingly difficult challenge. Consequently, although nanobiosensors will offer greater data to place more informed bets, it will still require skill in order to interpret such data to determine the correct outcomes. Moreover, due to the potential for corruption that exists within the sport, this data could be undermined anyway; as if for example a race is fixed, the selection of a race winner becomes almost impossible without insider knowledge. It is therefore clear that inaccuracy of human judgment and potential corruption can still result in misinformed bets; and chance still plays an intrinsic role in betting as a wider domain.

Despite this, the potential for the corruption of nanobiosensors for betting use is a significant issue and must be addressed. The potential theft of a horse's biological data, much like that of an athlete, may provide opponents with an unfair advantage; allowing them to identify potential performance issues and exploit them during the race. Further, the potential for improved bet forecasting could be detrimental to horse race betting, making it more formulaic and therefore less interesting, which could in turn result in betters wanting to bet on other sports in order to gain the 'thrill' of betting.

3. Universality

Much like in case study two, in order to determine the potential universality of this technology, it is worth considering the availability of existing biosensors. At present, biosensors are used widely through the sport of horse racing as vetenary tools, and are again commercially available to purchase without restriction in the public domain. Due to the potential vested interest in nanobiosensors for betting purposes, much like the sensors created by TPD (2013), it is likely that these will also be made commercially available for betting use.

There could however be issues in relation to the type of nanobiosensor a jockey, owner and trainer can access, which could generate potential inequality. Some may be contracted to a given betting company, and will require them to only use their sensor. This must be considered in order to promote equality within the sport.

4. Physical Prowess

The application of nanobiosensors to elite sport does not appear to present an issue in relation to physical prowess in horse racing. This is because its main role, much like its application for athletic use, is for performance analysis purposes, and therefore plays a supportive role and does not alter the nature of the sport. It instead offers essential performance analysis data to ensure that a horse remains in peak physical condition, but also protects its welfare. It furthermore provides additional biological data in order to place bets with. This does not detract from the physical prowess required to compete in the sport, as the horse is still required to run the race, and the jockey still required to apply their strength and skill in order to nurse it successfully around the course. The technology could however assist a jockey in establishing a stronger bond with their horse, allowing them to better predict when it is likely to be at its best and when it may struggle throughout the race, which will in turn promote improved levels of performance; pushing the boundaries of success, and boosting the quality of races. This would work to make races more competitive, increasing spectator entertainment (James 2010).

It could be argued that the technology has potential to deskill the sport, for example, making it easier for jockeys to identify when a horse is struggling. Yet this is only likely to present in training, where data stops can be conducted in order to improve performance. The jockey would not have this during the race, and will have to rely on skill in order to be successful. Thus, it would be difficult to challenge this technology on the basis of physical prowess.

4. Moving Forward – To Ban, Regulate or Keep the Status Quo?

After considering the above discussion, each of the nanotechnological examples presented via the case studies conform to the key elements of the IPC model (WPA 2018). Each case study example fails to present significant issues relating to fairness, universality, safety or physical prowess. Consequently, it would be challenging to describe such examples as forms of technology doping at present, as they do not offer a significant advantage in relation to levels of performance. Neither do they undermine the integrity of sport or remove the need for an athlete to apply key virtues such as effort and skill. Therefore, these nanotechnological examples could be argued to be a beneficial assistive technology within their given sports, further promoting the progression of the field.

Albeit, there were challenges presented in the above discussions that must be effectively dealt with in order to ensure the continued protection of the integrity of sport. Additionally, issues relating to corruption, toxicology risks and potential for unequal access in the initial period must be effectively governed in order to prevent their continued proliferation. Further, what each example promotes is the continued ability to micro-manage performances. Although this may sound irrelevant, such small gains are often the fine margins between winning and losing at the elite level, and as the technology develops further, it may enter the realms of technology doping, devaluing a given performance. Subsequently, if left unaddressed, these risks could eventually pose a challenge to the integrity of sport, allowing athletes and coaches to increasingly micromanage levels of performance (whether that's allowing an athlete to cut a few seconds off a sprint or a cyclist increase speeds on a straight for example), hence, increasingly undermining the values and purpose of elite sport.

Additionally, due to its infancy as a technology, and current lack of real-life application (in relation to case study two and three) the full extent of the disbenefits of this technology is still unknown. Although at present the nanotechnological case examples are not seen as means of technology doping, this does not mean that with further development they won't be in future. This technology's evolution has far from stagnated, and there are still considerable knowledge gaps in relation to its ethical impact on elite sport. It has already presented early warning signs of its ability to unsettle the fine balance between man and machine (entering the realms of technology doping) as shown via the aforementioned Speedo LZR Racersuit, which was banned after its implementation on grounds of technology doping; reducing the physical prowess required to compete at swimming's elite level, undermining the spirit of the sport (Dorey 2012). This highlighted FINA's clear discomfort, and lack of precautionary regulatory procedures in governing a new material technology such as this, with the act of banning (often a last resort) having been implemented; forcing an end to the potential benefits that the technology could generate if effectively governed within the sport (Dorey 2012). This raises concerns as to whether existing regulation deployed by sporting bodies are effective enough to deal with the potential of nanotechnology, and therefore maintaining the status quo could be a risk for bodies within elite sport.

One particular action that could be taken in order to limit the potential disbenefits raised by the case studies above would be to implement bans. However such action would seem unnecessary, especially as no rules have been broken, and subsequently its use cannot be viewed as cheating. Further it could even be seen as counter productive, preventing the benefits that nanotechnology may bring in terms of new levels of performance, safety and new financial revenue streams. It may also result in a reduction of future development, removing the motivation for further research into technological innovation (James 2010). Moreover, acting in such an absolutist manner often fails to solve the problem, as it is regularly the case that organisations, teams, coaches and athletes will simply look for additional loopholes in order to reintroduce the technology back into the sport, generating greater challenges for a given sport.

It would appear that the best way to ensure that the integrity of sport remains protected as this technology continues to evolve and develop is to apply regulation in order to govern its use within elite sport (particularly in reference to the examples considered in the case studies). Although it offers clear benefits, the disbenefits cannot be ignored, and therefore effective measures should be taken, in order to promote the benefits of this technology, and reduce the potential for it to become a means of technology doping. This should take the form of a specific regulatory framework for nanotechnology's use within elite sport. However, if after such regulation has been implemented, and this technology still enters into the realms of technology doping (and the spirit of sport is seen to be at significant risk, despite additional regulation) then more absolute methods of regulation should be considered, such as bans or rule changes in order to protect the nature and integrity of sport.

However, such frameworks take long periods of time to establish, and until our knowledge in relation to the risks associated with this technology improve, its may be unsuitable to establish one at present. This does however create a regulatory gap, where early examples of this technology such as those outlined in the case studies are integrated into elite sport without regulation. Therefore, until a framework is established, it is essential that precautionary measures be taken during any interim stages to promote the safe and ethical early application of nanotechnology in its various forms to elite sport - both in relation to athlete welfare and the sporting system as a whole. This will also help to raise the profile of ethics within technological development in sports, so that it is seen as an essential element of sports governance.

5. Conclusion

It is clear that the nanotechnological case examples discussed in this work provides elite sport a number of significant benefits, and could work to evolve differing areas of sports engineering. After considerable analysis and the application of the IPC (WPA 2018) technological framework, it would seem unfair to consider these technologies as forms of cheating, as at present no rules have been breached. Further, they are unlikely to be considered as methods of technological doping as at present, as they are expected to be universal in nature - in most cases improving safety, unlikely to generate significant fairness issues, and do not appear to alter the physical nature of a given sport (WPA 2018). Thus, nanotechnological examples such as these are more likely to fall into the category of progressive assistive technologies, which have been key to the continuous evolution of elite sport throughout its history.

Despite this, each case study also generated early warning signs via the identified disbenefits. Due to the infancy of nanotechnology, and subsequent knowledge gaps that exists in relation to it as a technology form, there are still a significant number of unknowns in relation to its potential use, application and ethical impact on elite sport. Further developments of this technology could therefore see it potentially move from being an assistive technology to a form of technology doping. Precautionary measures should therefore be adopted in order to regulate the initial integration of this technology, allowing us to establish specific risks that will in turn seek to inform the development of a future regulatory framework, limiting these potential risks from occurring. In the next chapter a precautionary measure will be presented for the initial regulation of nanotechnology into elite sport, that being the PP.

Chapter 9 - The Application of the Precautionary Principle

1. Introduction

In the previous chapter, a case was made for the implementation of precautionary measures in order to effectively manage the interim period of nanotechnology's integration into elite sport. An approach such as this would seek to improve governance practices, ensuring that the integrity of sport remains intact, whilst affording time for the development of specialised regulation. Furthermore, bridging the current regulatory gap that exists between the time in which a distinct regulatory framework may be established, and the continued integration of nanotechnology to sporting equipment. A case will now be presented for the use of the PP in order to fulfill this role, promoting the continued protection of the purpose and integrity of elite sport from any potential interim risks presented by nanotechnology (particularly in reference to the case study examples). This will allow for the establishment of an additional line of protective governance, which at present does not exist in relation to nanotechnology's use in elite sport.

Before consideration and justification of the application of the PP to govern the interim periods of nanotechnology's application to elite sport, this chapter will begin by offering an overview of the PP. Initially, this will not have a particular focus on its potential application to elite sport, but will instead provide an essential knowledge foundation in relation to this principle's origins and applications. A literature review discussing the debate that surrounds the PP's use will be examined, concluding with a defense of its continued use as a regulatory tool.

2. The Precautionary Principle – An Overview

There are significant challenges facing modern policymakers, particularly those working closely with new and emerging technologies. This is mainly due to their ever-evolving nature, making it difficult to calculate the potential risk outcomes that may be generated by the technology, as this is very often unknown until we have clear evidence of its impact in practice. In turn, this generates scientific uncertainty, which could result in the undermining of a given field of research, or worse, exposing human life and the environment to irreversible risk (EC 2017). Consequently, in order to address issues such as these, and promote good governance practices in times of uncertainty, many have employed the PP. This principle is designed to support decision-making in times where extensive knowledge of given outcomes are unknown (EC 2019). Thus, allowing for a precautionary approach to be taken that is centered around the notion that regulatory intervention to protect both the environment and human life is legitimate, even if the supporting evidence is lacking, speculative, or the economic cost of regulation is high (EC 2017; Kriebel et al. 2001). There are many reasons for the implementation of this principle, however the European Commission (2000, para 4) presents the following reasoning:

> *The precautionary principle may be invoked when a phenomenon, product or process may have a dangerous effect, identified by a scientific and objective evaluation, if this evaluation does not allow the risk to be determined with sufficient certainty.*

This regulatory principle should therefore only be applied when the risks of an action are deemed to be plausible, and should be subject to review if and when any new scientific data is presented. Practice such as this allows for modifications to be made to the principle, or for it to even be abolished if necessary, in the light of any new evidence (EC 2018). The role of the PP is therefore not to inform decision-makers or other policy makers on what to do or when to do it, nor does it reverse the burden of proof, but requires the proponents of a certain choice or activity to prove that it is free of risk (Ellis and FitzGerald 2004). Further, it does not place ideas such as environmental concerns for example, above social and economic standpoints, but instead proposes a course of action to be followed where there are environmental or human health concerns (Ellis and FitzGerald 2004).

Since its initial conception, the principle has undergone significant evolution, and is now often separated into two distinct variants, ‘weak’ and ‘strong’. The weak variant refers to the notion that regulators should actively want to address risk in times of scientific uncertainty, even if knowledge relating to the nature and full extent of that risk is still relatively unknown (Sachs 2011). Therefore, it maintains that the lack of scientific evidence does not preclude regulatory action if the damage of such actions could be serious or irreversible (NEW 2017). This form of action does not inhibit the potential application of a technology to society when a risk presents itself, but rather looks to guide the integration process in a controlled and safe manner so that the benefits are exploited, and the risks avoided (NEW 2017). Humans practice this sort of precautionary measure everyday in order to avoid hazards, and manage risk. For example, the vast majority of people would not deem it sensible to walk in a known dangerous area late at night; we exercise precaution to avoid potential health conditions such as eating healthily, and we buy smoke detectors to avoid fires and increase our chances of survival (Goliath 2002). In each case, we are not preventing a course of action from taking place due to the risks, but instead deploying methods in which to reduce the potential for the risks associated with each action. For example, driving in general is inherently risky, and if we feared all risks associated with it, we would never drive; in fact, we could probably justify banning it due to the dangers it presents to human life (Goliath 2002). But we do not; instead we accept the risks of driving due to its benefits of offering increased social mobility, and instead opt to deploy safety measures in order to reduce the opportunity for risk, such as the integration of safety features (e.g. seatbelts, airs bags and roll bars) into the design and construction of modern cars (Goliath 2002).

In contrast, the strong variant of the PP stipulates that regulation should be implemented whenever there is a potential risk to health, safety or the environment (Sunstein 2002). This should be actioned even if there is a lack of supporting evidence, or the evidence that is available is speculative, resulting in potentially high regulatory costs (Sunstein 2002). Conversely, the strong version of the PP suggests that precautionary regulation should be put in place as a default response during times of scientific uncertainty (Sachs 2011). Further, unlike the weak version, it is not only triggered by threats of serious or irreversible damage to both the environment and human life, but by any type of risk that a technology may present, making it a far stricter regulatory approach (Sunstein 2002). Examples of regulatory actions that could be imposed by the strong variant of this principle vary considerably, and can often be extreme in response, from a blanket prohibition of a technology/dangerous activity for example, to restrictions and warnings (Sachs 2011). To demonstrate this, a strong version of the PP would call for measures to lessen the risks of environmental harm driven by climate change, through preventive measures of reducing or preventing entirely the risks of emissions of greenhouse gases (NWE 2017). This could involve a complete ban on cars or air travel which would help to solve the problem; however at present, without the correct infrastructure in place, would also create a considerable number of other issues that would also need resolving. Consequently, the strong version of this principle is often described as the ‘no-regrets’ principle, where cost, seriousness of risk, or the potential to restrict future technological evolution are not considered as preventative reasons for the lack of action (NWE 2017).

Since its conception as a regulatory principle, policy makers have utlilsed the PP in different ways across a vast range of fields of study, such as health protection, environmental regulation and governance of new and emerging technologies (EC 2017). This is due to its flexible nature, particularly in its weak variant; offering a layer of protection in order to reduce the potential risk to human life and the environment, particularly during the interim stages of a new technology's introduction into a field of research. Thus, allowing time for viable scientific data to be established in order to make more informed regulatory decisions, and establish a specific regulatory course of action.

3. The Origins and Development of the Precautionary Principle

The origin of the PP is of great debate, with some arguing that it is thousands of years old, due to the idea of precaution being found in the oral traditions of indigenous peoples (Percival 2006). Whilst others have traced the idea back to the 1854 cholera epidemic, whereby Dr John Snow acted using precaution through his decision to remove a handle from a water pump in order to try and end the spread of cholera (COMEST 2005). Although the evidence at the time which suggested the causal link between the cholera epidemic and contact with the water pump handle was weak, Dr Snow’s simple yet effective action proved highly effective in preventing the further spread of the disease, and therefore is seen as a clear example of a precautionary act (COMEST 2005).

Despite these early examples of precautionary measures, the PP is generally considered to have emerged in the late Twentieth Century, with its roots traced back to the concept of *Vorsorgeprinzip* (meaning 'principle of foresight and planning') developed in Germany in the 1970s; implemented to prevent air pollution from damaging forests (Percival 2006, p.4/5). This subsequently led to a law being passed in Germany in 1974 which ensured that air pollution whenever possible was to be kept to a minimum, whether it be from chemicals or excessive noise (COMEST 2005). Later in 1984, the German Federal Interior Minister explained the term *vosoge* in greater detail, stating 'the principle of precaution commands that the damages done to the natural world (which surround us all) should be avoided in advance and in accordance with opportunity and possibility' (COMMEST 2005, p.10). However, taking actions in order to prevent harm to the environment via a precautionary approach is not new, as these concepts were illustrated in environmental statues in the 1960s and 70s in numerous countries (Percival 2006, p.6). Yet it was only during the 1980s where the term PP was used formally during its official application to a number of agreements to protect the North Sea from dangerous substances, enforced via a precautionary approach (Percival 2006; COMEST 2005).

Once formally established, the PP was later given International status when it was included in the Rio Declaration at the 1992 Rio Conference on the Environment and Development (CEE 2000). This provided the principle with International acceptance, and was signed by 178 nations (Percival 2006); Principle 15 of the Rio Declaration stated that:

> *In order to protect the environment, the precautionary approach shall be widely applied by States according to their capability. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation". Besides, the United Nations' Framework Convention on Climate Change and the Convention of Biological Diversity both refer to the precautionary principle. Recently, on 28 January 2000, at the Conference of the Parties to the Convention on Biological Diversity, the Protocol on Biosafety concerning the safe transfer, handling and use of living modified organisms resulting from modern biotechnology confirmed the key function of the Precautionary Principle* (CEC 2000, p. 10).

The PP has since been expanded to include human risk as well as environmental (CEE 2000), meaning any potential risk to either must be dealt with safely and appropriately in order to prevent any long term and irreversible damage from occurring. Further, since the Rio Declaration, there have been numerous variations of the PP generated. Yet, despite these variations, there are still common elements recognised at the core of each definition. These include:

1. *The need for scientific uncertainty.*
2. *The need for scientific analysis and the use of scientific data. Yet due to the fact that the precautionary principle deals with scientific uncertainty, "the quantified possibility is sufficient to trigger the consideration of the PP".*
3. *The need for intervention is required to take place before any harm or certainty of harm can occur, with that, intervention must be equal to the level of the possible risk.*
4. *The need for continued research after the intervention to gain a better understanding of the 'risk' at hand; to enable a more traditionalist risk management system such as risk/benefit to be achieved* (COMEST 2005, p.13).

It would therefore be fair to conclude that the PP is an established regulatory principle within International law, and one which has regularly been called upon in numerous fields in order to address risk, or policy debate (Ahteensuu 2007). Thus, it has been utilised when governing areas such as the protection of the ozone layer, to the development of modern biotechnology; demonstrating its universality as an ethical governance principle (Ahteensuu 2007).

4. Limitations and Defenses of The Precautionary Principle

Despite the PP having been established in International Law, there are still many who oppose its use as a regulatory principle, arguing that it is a limiting method of governance. Therefore, in order to promote effective research and academic rigour in relation to this body of work, such limitations will be addressed, alongside contrasting defenses of the PP. This debate centres around arguments relating to vagueness, incoherence and adverse effects during application (Ahteensuu 2007).

4.1 - An Argument from Vagueness

The argument from vagueness is the most common stance against the PP, stating that due to its lack of a universally accepted definition, it is not strong enough to be used as a regulatory tool and therefore should be abandoned (Ahteensuu 2007). There are many versions of the PP, all of which differ in wording and consequently meaning

(Manson 2002). Hence, without a clear-cut definition, it is very challenging to apply the PP in a regulatory situation, and equally as hard to determine the circumstances in which it can be activated (Jordan and O'Riordan 1999). The concern surrounding its lack of specific definition also generates additional issues relating to the level of precaution that should be applied when activated, as it does not clearly state the amount of precaution that should be taken at any one time in a given situation (Bodansky 1991). In its strongest form, the PP requires complete proof that there is no possible risk before a technology can be developed (Foster et al. 2000). Yet in its weakest form, it allows for greater flexibility, providing the opportunity to apply a cost/benefits analysis when making a discretionary judgment (Foster et al. 2000). This has a further knock on effect, as it does not clearly state the quantity of evidence required to activate the PP, or the level of action that is required when used (Foster et al. 2000). It may therefore be argued that as a regulatory principle it is dogged by vagueness and lack of certainty, which means effective application and use in a given situation is not possible; undermining its effectiveness as either a moral or regulatory principle (Turner and Hartzell 2004).

In spite of arguments relating to its vagueness, it could equally be argued that denying the use of the PP on such grounds would be unjust, and unfounded. This is due to an argument that the PP's lack of definition could actually be a strength; as long as it remains ill defined and challenging in terms of its transference into distinct codes of conduct, it offers greater flexibility as a principle, and increases the opportunities for its application (O' Riordan 2004). In addition, the amount of precaution used and evidence required in a given situation allows for cases to be dealt with on an individual scale and level; offering a far more bespoke approach to regulation than simply taking a 'one size fits all' approach, which can often be limiting and fail to address the complex benefits/disbenefits that new technologies may generate. This could promote improved regulatory action by ensuring that the actions taken are best suited to resolving a given situation. Moreover, the issue of 'vagueness' is far from unique to the PP, and is in fact also common to other regulatory policies (Sandin et al. 2002).

The argument to prevent its use as a regulatory principle based on the challenge that it lacks precision would also imply that we would have to stop also using other regulatory decision-making tools that also have the same issue. In turn, limiting our available options when presented with issues that may present risk to the environment or humanity. If opponents are to provide justification of avoiding the PP on the basis of vagueness, then they will also have to give reasoning in relation to other principles' relevant vagueness, and how it may be viewed as more problematic (Ahteensuu 2007).

4.2 An Argument from Incoherence

The second argument put forward by those who challenge the PP is that of incoherence. This is expressed by Holm and Takala (2007, p.1) who argue the following:

> *P1. We know that A (e.g., global warming) is a bad (or extremely harmful) for the environment.*
>
> *P2. We suspect that x (e.g., the emission of greenhouse gases) causes A, but this cannot, for the time being, be scientifically proven.*
>
> *C1. We conclude that, in the name of precaution, we ought to ban x, even though it may turn out that it is not the cause of A.*

Therefore the PP could be seen as problematic, particularly in its strong variant. This is because it is possible to justify risk decisions to be made without sufficient evidence, and for bans to be activated that may not actually increase safety, but could in fact result in the stifling of progress. Further, if the PP is critically evaluated, it could be argued to be absolutist in nature, and therefore could be used to ban anything that presents risk, or additionally used to justify the banning of any new concept or technology; which could continually block human evolution (Holm and Takala 2007). It could therefore be argued that the PP is problematic, particularly in its strongest form, as is appears to lack flexibility and could actually inhibit essential developments based on the smallest amount of risk. The principle aims to offer flexible regulatory guidance, yet arguably has failed to achieve this, as it simply condemns the very steps that it requires. The regulation required by the principle often generates its own risks, therefore paralysing actions and preventing progression (Sunstein 2000). Thus, the PP could be interpreted as a blunt instrument used to ban anything on limited evidential grounds *(*Brown 2013); and so instead of providing an informed real world regulatory option that considers the potential implications of both doing something and not doing something as it advocates, it instead offers simplistic bans when confronted with challenges (Brown, 2013).

Again, this argument can be seen as problematic as proponents of the PP have disputed that the argument from incoherence is not valid or fair. Sandin (2004, p.468) counters the criticism that the lack of true definition can lead to incoherence by arguing the following:

> *Despite differences, many formulations of the precautionary principle share four common elements, which I have elsewhere (Sandin 1999) termed 'dimensions': (1) the threat dimension, (2) the uncertainty dimension, (3) the action dimension, and (4) the command dimension. These formulations can be recast into an if-clause of the following kind, containing these four dimensions.*

Therefore, the point Sandin (2004) makes, is that despite the varying definitions, there is a basic level of universality to the PP that is accepted Internationally. Consequently, arguments in relation to incoherence are not a valid excuse to avoid using it. It could also be argued that those who criticise the PP based on incoherence are confusing it with a regulatory policy; as the PP is not regulatory policy, but rather a supportive action. Reaffirming that regulatory actions put in place such as this should be progressive in identifying serious risk to both humanity and the environment (Percival 2006).

Further, an argument could also be generated that incoherence could actually be considered a strength of the PP. The reason being that like other widely discussed principles ("sustainability", for example), the PP can be interpreted in different ways, allowing it to be drawn together in a wider coalition of support so that it can act as a focus for political action in support of desirable policies (Hughes 2006). Ahteensuu (2007, p.372) supports this point, stating the following:

> *If one takes a look at the formulation of the PP found in official documents and in the academic commentary literature, it becomes obvious that the definitions of the principle per se are not contradictory. The PP – as commonly defined – does not simultaneously state that precautionary measures should be taken and should not be taken. Thus, the principle is not incoherent in this sense, and the possible incoherent formulations can be revised.*

Incoherence such as this may actually be avoided without cancelling out the PP, but by employing a second level of risk evaluation. This would act as a running control for any action taken in order to avoid significant difficulties when applying this principle (Saner 2002). Moreover, if its application were conducted in a reflective manner, it would work to reduce any concerns relating to its potential incoherence (Sandin et al. 2002).

4.3 An Argument from Adverse Effects

The third and final argument against the PP is that its application, instead of reducing potential adverse effects, would actually work to promote them. This is a view that Fuller (2013) discusses, arguing that the PP is very much the skeptic in the room, which is often based on outdated information models, and thus making it short sighted with the possibility of generating more harm than good as we enter into the future. Therefore, the PP could inadvertently produce adverse effects, as acting in a proactive manner without a true understanding of the situation could result in us overlooking potential benefits in favour of the risks, limiting or even potentially damaging future human progression (Fuller 2013). As a consequence of this, some are not advocating the PP as this validates calculated risk-taking as essential to human progress, whereby the capacity for progress it taken to define us as a species. Hence, suggesting that by acting in a precautionary manner, we are actually putting humanity at greater risk by preventing radical experiences that have in the past resulted in major leaps in knowledge (Fuller 2013, p.3).

Several argue that this issue has already had an impact on the fields of medicine and the pharmaceutical industry, as although advancements have clearly been made, a clear reduction in the number of innovative drugs may be witnessed via the commercial market; resulting in less curative treatment available, and consequently impacting humanity (Walport 2012). This is due to stricter regulation (possibly via the implementation of the PP); where drug regulators are increasingly afraid of making errors in judgment relating to risk. Consequently, projects may be brought to a close rather than researched further if risk is presented (Walport 2012). In such, the PP is argued by some to be 'anti-research' as it fails to accept risk, which is essential, particularly in fields such as medicine. Furthermore, the PP could be seen to be shortsighted, and therefore its implementation could have unknown or potentially harmful knock on effects for both the environment and human life at a later stage.

For example, if applied to innovations such as the polio vaccine, regulators may have denied the approval of its use purely on the basis of its occasional side effects at the expense of millions of lives that were saved from its success (Ahteensuu 2007).

Although this argument generates a number of valid points, it can again be countered. As previously discussed, there are differing versions of the PP, and not all hold this paradoxical limitation. This is because arguments from unwanted consequences are often based upon more conservative stronger versions, which fail to take into account the weaker versions of this principle, allowing for risks to be taken as a long as they can be justified (Hughes 2006). Therefore, the implementation of the PP does not necessarily need to result in adverse reactions, and can actually work to promote progress in a safe and ethical manner. It could furthermore be argued that adverse effects driven by the PP could actually be avoided, as if the initial risks and implemented precaution risks are considered equally without simply imposing one without thought, then a decision can be made that promotes a positive course of action. Moreover, the PP may encourage the use of more advanced and safer scientific research by insisting on greater levels of understanding and testing to bridge knowledge gaps in order to reduce future risk (Ahteensuu 2007).

Another counter point to challenge the adverse effects argument may be evident when considering examples of past human events, where the lack of early action driven by the desire for progression has actually resulted in negative impacts, both in relation to human life and the environment (Harremoës et al. 2000). A prime example of this may be seen when considering asbestos, which became prevalent as a building material due to its advantageous properties such as its ability to be fire and heat resistant (Doll and Peto 1985). Asbestos was consequently mined in huge quantities despite early health warnings of the material presenting as early as 1898, whereby Lucy Deane a UK Factory Inspector noted the sharp nature of asbestos particles under microscope, stating that they may pose a risk to public health (Harremoës et al. 2000). Yet such warning signs were dismissed due to a lack of causal evidence, and arguments generated that its continued use and development should not be prevented based on unquantifiable health risks. However, as our knowledge of asbestos improved, the early health risks were soon quantified; resulting in the UK government banning the use of white asbestos in 1998, a ban later supported by the EU (Harremoës et al. 2000). Due to this lack of action and early precaution, the human damage of asbestos is still being felt today. The current asbestos induced death rate in the UK is approximately 3000 deaths per year, and 250000-400000 asbestos cancers are expected in Western Europe over the next 35 years due to human exposure (Harremoës et al. 2000). Some argue that the impact of asbestos on human life may have dramatically reduced if early concerns were taken seriously, and research undertaken using precaution (Harremoës et al. 2000). Therefore, even though the PP could be argued to generate risk through adverse reaction, it can equally be argued that its lack of application can also generate high risk to both human life and the environment.

Finally, the application of the PP does not necessarily have to result in adverse effects, particularly if applied well. It can instead work to promote the idea that innovation is not a one-track race to the future, and that precaution can actually help us think around a problem; creating more advanced solutions than before (Bell 2013). It may also promote the practice of 'good science' and regulatory action, helping to support and promote effective research, and therefore limiting the chances of potentially adverse or unwanted effects in the future.

After considering the lines of argument in relation to the PP, it is clear that there are valid points made on both sides of the debate. The PP, particularly in its strongest form, does present the potential to be a preventative method of regulation, and could be used to inhibit human development through the promotion of bans when any form of risk presents itself, even if such risk is minor in relation to the benefits of a given development. Consequently, it can be understood why many within the field of science for example may oppose its use, as it may be used to limit or even stop scientific development. Failing to take into account that any new development, particularly in relation to a new technology, always presents an element of risk. Yet despite this, it could equally be argued that that 'development requires risks' argument is very naive; as this approach has had serious consequences in the past, with a prime example being the aforementioned case of asbestos. Therefore, whenever a new human development emerges such as asbestos, or in this case nanotechnology, there must be an essential weighing up of the risks and benefits in relation to its continued development. Further, when risk is presented, there must also be, in a sensible manner, promotion of the safest course of action to be taken. This does not simply imply bans, but could be other forms of regulation, which does not imply a limit on progression, but ensures it is done so in a safe and ethical manner.

This is why the weak version of the PP holds such value, as it offers a sensible, everyday day approach to regulation, which is essential when managing any new and emerging technology. Furthermore, in contrast to its strong counterpart, it can be applied to actively promote future advancements, but ensuring that this is done in a safe and ethical manner. Therefore when risk does present itself, it is addressed within its specific context, allowing for a reasonable course of action to be taken depending on the given situation. This allows it to play a supportive role in regulation, going against what has been suggested by those who oppose it (who arguably are mainly criticising the strong version of this principle, and not the weak). Hence, it would seem unjust to simply rule out this principle as a potential governance tool, and if used in its weak variant and in a sensible manner, it can provide a highly effective layer of ethical governance in overseeing the introduction of any new technology, such as nanotechnology's initial integration into elite sport.

5. Applying the Precautionary Principle to Govern Nanotechnology

Now that a knowledge foundation of the PP has been established, this chapter will next consider how this principle could be applied to govern nanotechnology's initial integration period into elite sport in relation to the case studies. In order to do this, this next section will be divided into two additional subsections. The first will consider *why* this principle should be applied in order to bridge the current regulatory gap in relation to nanotechnology’s application to elite sport; and the second will consider *how* it could be applied in order to safely govern nanotechnology’s initial integration into elite sport.

5.1 The Importance of Applying the PP to Govern Nanotechnology's use in Sport

Nanotechnology offers a number of advantageous benefits to elite sport that are hard to ignore. After extensive consideration in the last chapter, its application cannot be construed as a form of technology cheating or (at present) doping. However, despite this, the risks presented in the previous chapter should not be ignored, as the infancy of nanotechnology means that such risks could easily transform into far more significant ones as we enter into the future. This could in turn represent a challenge to the integrity of sport. Therefore, disbenfits such as this must be taken seriously to ensure that all stakeholders, and the integrity of sport itself, continues to be protected from any current and future potential risk that could be associated with this technology, within the context of the case studies and beyond.

In order to offer a level of protection to limit the potential risks identified in relation to the integration of this technology, it would therefore be deemed wise to apply a governance framework to oversee its integration into elite sport. It is evident that there exists a difficulty in doing this, as due to existing knowledge gaps, and the uncertainty surrounding nanotechnology's future potential, developing a specific nanotechnology regulatory framework is likely to be highly challenging. Therefore, in order to govern its initial integration into elite sport, a flexible framework should be applied, which in this case I argue should be a weak version of the PP. The strong version of this principle has been ruled out due to its limiting approach to regulation, and lack of clarity in relation to the scale of governance that should be applied in order to govern each risk presented. Further, its use could justify blanket bans, which at present, nanotechnology's use within elite sport does not present enough risk to justify. Application of this variant of the principle would promote nanotechnology's safe integration within elite sport, allowing for its progression to continue in order for sports engineers to exploit its benefits, whilst ensuring that this is done in a safe, controlled, and ethical manner. Thus, when this technology does present risks, as identified when considering the case studies in the previous chapter, they are addressed in a sensible manner to ensure that the individual athlete, and sport as a whole is protected.

The PP has yet to be applied as a mode of sporting regulation, and has mainly been confined to those fields that may impact human life or the environment directly such as medicine, engineering and power production. Despite this, it could be equally argued that the principle has a universal application, and that its notion of offering safety in times of uncertainty is equally applicable to the world of sport as it is to that of medicine (Ahteensuu 2007). As stated previously, its lack of true definition promotes its potential application to any number of fields of study, and therefore does not limit how and where it could be used. Therefore, instead of simply being implemented in order to govern technologies from causing irreversible damage to the environment or potential loss of life, it could equally be applied to protect the integrity of sport from irreversible damage. In addition, there is arguably a cross over in relation to its use in elite sport and its key value of protecting human life and the environment. The manufacturing of nanotechnological sports equipment appears to present a potential toxicology concern, which could put those working directly on the manufacturing lines at a potential health risk. Consequently, the application of the PP in order to govern this risk would be no different from its use to oversee the emergence of new and untested medicines that may pose human health risks for example. The same could be said when considering the use of nanobiosensors for the collection of biological data. Not only on the grounds of potential toxicology concerns for athlete, but also due to the prospective for corruption or misuse of the data collected, which could result in harm to an athlete in relation to their career prospects and emotional wellbeing. This could also apply to the use of nanobiosensors for horse racing, as the purposeful or accidental misreading of a horse's biological data could result in changes being made to their diet, or training that could potentially put its health at risk. Again, this is arguably what the weak variant of the PP has been generated to deal with.

Finally, this principle's application in order to protect the environment may also come into play due to our limited knowledge as to how nanomaterials may impact with the environment; therefore, ensuring that irreversible damage is avoided by placing nano sporting equipment into landfills for example (Biddlecombe 2015).

Although the PP was not originally designed in order to govern sporting applications, its universal and flexible nature means that there is clearly an opportunity for a weak version of the PP to be molded for the purposes of governing nanotechnology's initial integration into elite sport, which in turn could work to ensure its safe and ethical application.

5.2 How to Apply the PP to Govern Nanotechnology's use in Sport

This following section will be subdivided in two, both of which will outline potential methods of applying a weak version of the PP in order to govern nanotechnology's initial integration into elite sport. The first will consider its potential use in governing the manufacturing stages of 'nano' sporting equipment. The aim of which is to promote its safe and ethical production, limiting the risks presented to individuals and the environment, and the integrity of sport as a whole. The second section will then consider its application for the governance of nanotechnological sporting equipment’s use in and out of competition. Again, with the aim of protecting the integrity and values of a given sport until knowledge gaps are fully addressed, and specific regulation implemented.

I. Manufacturing

The consideration of potential governance of a new technology within sport is often conducted through reflection of its use both in and out of competition. Although in most examples of sporting equipment this approach is completely justifiable, as the risks presented via manufacturing processes are often extremely low, and nothing beyond that which is considered normal. This is not the case when considering nanotechnology, because as discussed previously, the manufacturing of nanotechnology (or nanomanufacturing) does present a number of potential risks, particularly in relation to both human health and the environment. Therefore in order to promote good governance practices, and ensure the continued protection of both the integrity and image of sport, a weak version of the PP should be extended in order to manage the current regulation of nanomanufacturing for sporting equipment purposes, such as elite road bikes and nanobiosensors.

There are many models on which such a precautionary approach could be based; a prime example is one which has been developed and implemented by the Swiss Federal Office of Public Health and the Swiss Federal Office for the Environment, who have implemented a precautionary matrix[28] for the monitoring and regulation of synthetic nanomaterials during its manufacturing stages (Schomberg 2012). This precautionary matrix was developed to deal exactly with the issues presented in this body of work, as it relates to the manufacturing of products containing synthetic nanomaterials, and was designed to work within industries and trades, in order to provide methods of assessing nano-specific health and environmental risk of synthetic nanoparticles used in nanoproducts (FOPH 2018). The purpose of the matrix is to offer increased levels of safety in the development of new nano products, whilst also offering a preliminary risk assessment based on available scientific knowledge relating to the risks associated with nanotechnology (FOPH 2018). Further, it would support the identification of any potential sources of risk in the development, production, use and disposal of synthetic nanomaterials (FOPH and FOEN 2018). Once this matrix has been completed, and evidence in relation to the risk of a particular synthetic nanomaterial has been established. This matrix is finalised through a classification process, where nanomaterials are split into two categories:

> *"Class A": The nanospecific need for action for the considered materials, products and applications can be rated as low and does not need further clarification.*
>
> *"Class B": Nanospecific action is needed. Existing measures should be reviewed, further clarification undertaken and if necessary, measure to reduce the risks associated with development, manufacturing, use and disposal implemented in the interest of precaution (FOPH and FOEN 2018).*

Once a classification has been established, the matrix can then be used to identify the specific safety needs for the health of workers, consumers and the environment, by taking into account the life cycle of nanomaterials in relation to research and development, production, use, and waste disposal (FC 2008).

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[28] A full version of this Matrix is located on page 11/12 of the The Federal Office of Public Health (FOPH) and the Federal Office for the Environment (FOEN) (2018) *Guidelines on the Precautionary Matrix for synthetic Nanomaterials Version 3.1*.

This framework therefore embraces a weak version of the PP, and rather than stifling developments in relation to products containing synthetic nanomaterials, it embraces it. It also ensures to monitor such developments in order to promote high levels of safety for both human life and the environment, so when risks do present themselves, procedures can be put in place in order to reduce the potential for long term and irreversible damage. This framework would therefore be ideal for application to the regulation and monitoring of health and environmental risks associated with developing nanotechnological sports equipment, such as bikes and nanobiosensors for example. Further, the matrix is universal in nature and could easily be promoted and adhered to by sporting bodies working in collaboration with manufactures to ensure the highest levels of precautionary measures are achieved, promoting the safety of workers and the environment. This matrix could also be deployed in order to continually monitor the potential toxicology risks associated with athletes and horses wearing nanobiosensors, ensuring good practice beyond the manufacturing stages.

II. Application to Elite Sport

Once the PP has been applied to govern nanotechnology's manufacturing stages, its application to elite sport can then be considered. Again, a weak version of the PP should be applied to ensure that this done in a safe and ethical manner, ensuring that the athlete, along with the nature and integrity of sport is protected. In order to do this, it could be integrated into an ethical analytical tool for nanotechnology's application to elite sport. This additionally could apply an ethical catergorisation framework for determining the role/function of a piece of sporting equipment, such as the IPC framework (WPA 2018). Thereby adding another layer of effective regulation, in order to determine whether any new nanotechnological equipment is a form of assistive technology or that of doping. Consequently, when a new piece of nanotechnological sporting equipment is applied to an elite sport, it should be initially regulated through the application of such an analytical tool (unless it is in breach of sporting rules and determined a mode of technology cheating), an example of which is modeled below:

Flow Diagram 1: Ethical Analytical Tool for Nanotechnology's use within Elite Sport:

1. An ethical pre-mortem of the potential benefits and disbenefits (using knowledge available to sporting bodies) is to be conducted before any new nanotechnological piece of equipment is integrated into an elite sport. Once established, these benefits and disbenefits are then to be applied against an ethical catergorisation framework, such as the IPC[29] version (WPA 2018). This will allow for this equipment to be determined either as an assistive technology, or a form of technology doping.

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2. If after review against an ethical catergorisation framework, the nanotechnological equipment is considered a form of assistive technology. Then its application should be granted to a sport under the guidance of a weak version of the PP within an initial trial period. This will enable for further real outcome evidence to be gained in a safe and controlled manner. If at any point during this trail period risks are generated to the nature and integrity of a sport, trial should be stopped (in accordance to the PP) and additional ethical reviews should be conducted in order to protect the sports nature and integrity, both in relation to the athlete and sporting system as a whole.

↓

3. After this trial period has been completed, and real-life outcomes/impacts have been established, the technology should be re-reviewed against an ethical catergorisation framework. This will allow for secondary review to be conducted, promoting the ethical development of nanotechnology. This will further permit for comparisons to be made in relation to the benefits/disbenefits raised in the pre-mortem stages, in order to determine the accuracy of that initial process.

↓

4. If after this secondary review the equipment is still considered a form of assistive technology, continued application and use within a sport should be promoted. However, any potential disbenefits should be specifically regulated in order to limit any risk/potential shift towards a form of technology doping. Any specific regulation should be used to construct a 'nano' specific regulatory framework in order to govern nanotechnologies specific use within elite sport

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5. If the equipment after review is now considered a form of technology doping (either at the start of this decision tool or at this point) the technology should be prevented from being integrated into the sport. An ethical review of the reasons as to why it is considered a form of technological doping should be conducted, and alterations to the equipment should be made if needed to combat this issue.

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6. After this, the technology should be re-reviewed against an ethical catergorisation framework in order to determine whether such issues have been resolved. If now deemed an assistive technology, it should re-enter the framework as outlined above, and start the trial period.

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7. If still considered a form of technology doping after this process, a review should be conducted in relation to the extent in which it may challenge the values and spirit of a sport. If the impact is considered minimal, strict regulation should be imposed, and its use should still be allowed via an extended trial period. Yet if its impact is considered to be significant, and beyond regulation, then bans should be imposed in order to protect the integrity and nature of a sport.

[29] Alternative catergorisation frameworks with a similar function could also be applied at this point.

This analytical tool can be applied each time a new piece of nanotechnological equipment is developed and integrated into an elite sport. Consequently, allowing for a sensible and controlled approach to this technology's initial application to a given sport, reducing the potential disbenefits (along with also limiting the potential for technology doping) whilst simultaneously allowing for the benefits to be exploited. Further, each new piece of nanotechnological sporting equipment would be considered individually, on a case-by-case basis, promoting real life outcomes and consequences, allowing for the knowledge gaps surrounding nanotechnology's use within elite sport to be addressed (O' Mathúna 2010). Further, if disbenefits are generated, a weak version of the PP will provide an effective initial layer of regulation, allocating time for additional ethical reviews to be conducted, and more specific regulation to be put in place in order to protect the integrity of sport. Such an application of the PP via this analytical tool would additionally prevent the PP from being used as a blanket defense (a common argument against its use) and allow it to become tailored to each case, supporting the application of the right level of precaution, and challenging risks when they are presented.

Conversely, it could at this point be argued that such an analytical tool underpinned via a weak version of the PP could stifle nano technological development within elite sport, generating more 'red tape' that prevents the immediate exploitation of its benefits. This is a valid point, as its use would slow nanotechnology's initial integration into elite sport. Yet despite this, it still does not prevent its application and progression, but rather promotes nanotechnology's safe and regulated integration into elite sport. This in turn maintains that an athlete's welfare, and the integrity of sport are protected. It also ensures that lessons are learnt from past mistakes, where issues such as those posed by the aforementioned LZR Racersuit would be reduced, or even prevented before they are introduced. Furthermore, its underpinning by a weak precautionary approach would act as a safety mechanism to ensure that all stakeholders are protected from potential risks posed by this technology, both in and out of competition. Thus, acting as a focus for action, ensuring the development of effective risk management methodologies, and that knowledge gaps are identified and addressed in order to promote effective risk management and overall governance (Schomberg 2012).

6. Conclusion

Despite its humble beginnings as a regulatory principle developed for the monitoring of air pollution in Germany in the early 20th Century (Percival 2006), the PP has now become an integral element of International regulation used to prevent irreversible risks posed to both humans and the environment. It has since become particularly successful in the guidance and regulation of new technologies, ensuring to promote their safe and ethical integration into human society. Yet despite this, the PP has had its challengers, with some arguing that its use actually holds back human progression, where its strong variant is used to advocate bans when any risk presents itself, overlooking the potential benefits or opportunities for further development (Foster et al. 2000). The opposing view argues that this is a misinterpretation of the PP, as its weak variant allows for progressive and sensible regulation, promoting human development, but in a safe and ethical manner (O' Riordan 2004).

Consequently, the PP still holds value, and offers a universal nature making it a justifiable method of application in order to oversee the safe integration of nanotechnology into elite sport (Ahteensuu 2007). Particularly as there are still significant knowledge gaps with regards to our understanding of this technology, and we are still unaware as to how it may impact the fine balance between man and machine. Therefore as stated above, this principle could offer a method to govern nanotechnology's application to elite sport, in order to protect the integrity of sport, whilst also ensuring its safe and ethical manufacturing for its use in sporting equipment. Consequently, the integration of a weak version of the PP to the ethical analytical tool outlined in this chapter, would enable for the initial application of a nanotechnological piece of sporting equipment to be applied in a safe and controlled manner. Further allowing for more data to gathered in relation to the benefits and disbenefits this technology may present elite sport, allowing sporting bodies time to identify particular disbenefits, and establish specific regulation to govern them. Such governance can then be used to inform a future regulatory framework specifically designed for nanotechnology's use within elite sport.

Therefore the PP should not be viewed as a long-term regulatory solution to the issues presented by nanotechnology's use in elite sport, as its role is to act as a governance bridge for the initial integration of the technology, and should not be seen as a permanent fix. Thus, during the period in which the PP is in use via the analytical tool, sporting bodies should consider the risks that nanotechnology presents in order to establish specific regulation for its continued use within elite sport. This would allow for the PP to be slowly retracted once new knowledge in relation to this technology emerges, and replaced with a new and more suited course of governance if needed.

The next chapter will offer a range of specific regulatory solutions to the disbenefits raised via the nanaotechnological case studies discussed in this work. These may then be utilised by sporting bodies in order to potentially inspire and inform the creation of a specific nanotechnological regulatory framework.

Chapter 10 - Informing a Future Potential 'Nano' Regulatory Framework for Sport

1. Introduction

In the previous chapter, a case was presented for the application of a weak version of the PP via an ethical analytical tool, in order to govern nanotechnology's initial integration into elite sport. However, the use of such an analytical tool utilising the PP principle, should not be seen as a permanent governance solution. In order to slowly repeal its use, knowledge gaps must be addressed, and when disbenefits are presented via this process, specific regulation should be established and implemented in order to not only preserve the spirit of sport, but also to inform the establishment of a nanotechnological governance framework. Eventually this framework would consequently form the first line of defense in relation to nanotechnology's regulation, allowing for the PP to play a more supportive role when required. This would generate a dual layered regulatory approach, ensuring the continued effective governance of nanotechnology's use within elite sport, preventing it from becoming a means of technology doping.

This chapter will therefore model a series of regulatory actions that could be adapted in order to inform the development of a specific nanotechnological governance framework[30]. In order to do this, the disbenefits raised by each of the case studies discussed in this work will be considered, and a range of governance methods outlined in order to resolve them. Thus, this chapter will be split into three key sections, each of which representing one of the case studies. Each section will begin with a summary of the disbenefits raised in relation to the case studies in order to provide context, followed by specific regulatory solutions in order to potentially address such issues.

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[30] An important point to be made here is that this chapter will not attempt to present solutions to all of the disbenefits presented via each of the case studies. It will instead aim to address the main disbenefits presented via each of the case studies, identified via the IPC framework analysis carried out in Chapter Eight.

2. Case Study One - Potential Specific Regulatory Solutions

To summarise, the first of the three case studies centered around nanotechnology's application to an enabling technology, with specific reference to the race bike in road cycling. The following discussion will therefore outline a number of specific regulatory methods in order to address the disbenefits identified through the ethical analysis of this case study, which could then be used to inform the development of a potential future regulatory framework for nanotechnology's continued use and application to elite sport.

2.1 Promoting Fairness and Equality

In case study one, the application of nanotechnology to cycling raised disbenefits relating to equality and fairness, promoting the notion that it could prevent the best athlete from winning, and therefore undermine the purpose of the sport (Ostlere 2019a). One way in which this could be prevented is via the integration of regulatory standardisation polices. This approach has already been utilised within a range of sports such as sailing, where boats are divided into classes; and also javelin and the shot putt, where athletes are required to use the same equipment when competing (Loland 2002). The aim of which is to promote and ensure a level playing field, particularly in sports such as cycling, which are dependent on enabling equipment for their very existence. Standardisation would therefore help to maintain the already delicate balance between man and machine within cycling, ensuring that the technology plays a supportive role rather than a central one. This would also work to maintain that the success of an athlete or team is due to their hard work and efforts, rather than the advanced technologies that they may have access to in comparison to their competitors. It would additionally work to appease fans who are concerned with the increasing role technology is playing within the sport, and the potential impact on its competitive nature (Ostlere 2019a).

The concept of standardisation is not foreign to elite cycling; policies such as this are already commonplace within the sport, with all race bikes for example being required to meet the specific UCI (2017) technical regulations relating to the uniformity of specific parts, such as handlebar and frame size. Yet despite this, cyclists and teams have still been able to gain an edge over their competitors through the application of improved design technology, and the addition of advanced construction materials into race bikes that they use, which at present is not regulated or standardised (UCI 2017). In order to challenge this issue to further promote fairness and equality within the sport, material standardisation could be implemented in order regulate bike construction further. Consequently, if stakeholders within cycling such as the UCI, cycling teams, athletes and manufactures agree the use of nanomaterials as essential for the further progression of cycling due to its beneficial properties, then all teams and manufactures should be required to construct all new bikes from materials such as graphene for example (and be supported in order to address potentially high initial production costs). Consequently, ensuring that all athletes have access to the same technology, and preventing the potential for any early or exclusive access for some cyclists, which could in turn provide them with an unfair advantage over the rest of a field (Loland 2009). This regulatory policy could be taken a step further, with a full and comprehensive standardisation of all bikes used within the sport; dramatically reducing the potential for inequality and fairness issues through nanotechnology's application to cycling, further ensuring that an athlete's skills and efforts remain the main focal point of each racing competition (Loland 2002). Embodying an approach such as this does not imply an automatic limit on technological innovation within the sport (often the counter argument in relation to standardisation), as this has yet to become an issue in other sports that have deployed similar regulatory policies. Instead, it could actually encourage manufactures to work more closely in order to further improve the design and construction of the bike in order to mutually benefit all stakeholders. Thus, the emergence of new and advanced technology such as nanotechnology within cycling may mean that its integration into all bikes at elite level will enable the majority of athletes to access the potential benefits this technology may bring in terms of performance and safety, not just the minority. In addition, it would support governance procedures within the sport, particularly in relation to the deployment of new technical guidelines relating to the bike's design and construction.

2.2 Financial Fair Play and Protecting the Spirit of Sport

Cycling has historically been a well-funded sport, with those athletes and teams at the elite level regularly having access to the most up to date and sophisticated technologies. However, the status quo has been challenged in recent years, where funding gaps have increasingly emerged; a result of increasing financial strain on teams and owners (Pender 2018). This has resulted in the emergence of financial inequalities throughout sport, where many are now worrying that the wealthier teams will be increasingly able to 'buy' success by investing huge sums of money into technological research and development programmes, knowing that other teams/organisations cannot do the same (Ostlere 2019a). Consequently allowing them to exploit any new and emerging technologies that may enter the sport such as nanotechnology, leaving other less funded teams/organisations having to play catch up, putting them at a clear disadvantage.

This disbenefit is often referred to as 'financial doping', and has been a problematic issue within a number of alternative sports (Schubert and Hamil 2018). For example, American Football previously had an issue with wealthy teams simply being able to buy all of the best players in the league resulting in their dominance, which made games less exciting and highly predicable, with fans increasingly turning away from the game as a spectacle (Perritano 2001). Thus, in order to challenge this issue and further promote financial fair play, The National Football League (NFL) introduced a salary cap and draft system, preventing this issue from occurring, and enabling a much fairer selection process for new talent across the board within the sport (Perritano 2001). A similar issue has also been prevalent within football; where many examples of financial doping are evident. However, one of particular prominence was Roman Abramovich's investment into Chelsea FC after his take over of the club in 2003 (Schubert and Könecke 2015). His investment into the club caught the eye of the public, and until mid-2012, Abramovich allegedly invested over a billion Euros into the club (Gibson 2012a, cited in Schubert and Könecke 2015, p.70). Bayer Leverkusen and VfL Wolflsberg also demonstrate that the source of money does not need to be from private investors only (Schubert and Könecke 2015); within the German system there is currently a 50 + 1 rule that states that a club must ensure to retain more than 50% ownership, which in theory prevents any investor taking complete control of any given club (Schubert and Könecke 2015). This has not prevented 'financial doping' from continuing, with the enterprises Bayer and Volkswagen regularly providing financial means for each of their respected clubs (Schubert and Könecke 2015). On the face of it, practices such as this could be seen as legitimate, as in general money for clubs is provided either as direct 'injections', or as soft loans (Franck 2010, cited in Schubert and Könecke 2015, p.70). Moreover, in countries such as Spain and Italy, some local authorities indirectly support football clubs via soft taxation (Storm and Nielsen 2012), and so 'regardless of how and by whom the money is provided, all kinds of cash flow have in common that the money is provided "externally", that is, not based on the operative business of the clubs (Schubert and Könecke 2015, p.70). This is however not the key issue; what is, is the large extent of these practices that are considered a blurring of the competition by those competing, and hence considered 'financial doping' (Schubert and Könecke 2015).

In order to counter these issues, UEFA introduced Financial Fair Play (FFP) into football in 2010, with the aim of protecting the long-term stability of European Football (UEFA 2010; UEFA 2015). There are six main ideas of FFP according to UEFA (2015, p.2) as outlined below:

> a*) to improve the economic and financial capability of the clubs, increasing their transparency and credibility*
>
> *b) to place the necessary importance on the protection of creditors by ensuring that clubs settle their liabilities with players, social/tax authorities and other clubs punctually*
>
> *c) to introduce more discipline and rationality in club football finances*
>
> *d) to encourage clubs to operate on the basis of their own revenues*
>
> *e) to encourage responsible spending for the long-term benefit of football*
>
> *f) to protect the long-term viability and sustainability of European club football*

The FFP has therefore been implemented in order to raise standards of governance across Europe, by introducing budget constraints in order to force clubs into establishing a more solid financial conduct (Hill 2011, p52; Schubert and Könecke 2015). This has generally resulted in the prohibition of clubs from expanding more than the income they generate in a legitimate manner in relation to certain expense categories defined by UEFA[31] (Schubert and Könecke 2015). This implementation has been given official support by important and relevant stakeholders, such as the European Professional Football Leagues (EPFL) as well as the players unions such as FIFPro (UEFA 2009, cited in Schubert and Könecke 2015, p.76). Thus, this approach has helped to promote greater levels of equality in relation to the financial operations within the sport, seeking to prevent the dominance of wealthier teams.

As a result, if an option of standardisation were to be rejected, the UCI could consider the application of a financial policy inspired by actions taken by other sports such as those outlined above[32]. This could take the form of a potential *Technological Financial Fair Play Policy,* for example. This policy could be based upon a principle of strict equality, whereby every athlete competing within the sport would be entitled to the same level of material goods and services, as they are all seen as equal competitors (Lamont and Christi 2017; Brown 2015). In contrast (and more preferable), it could be based upon a principle of Fair Opportunity, which states that 'persons should not be treated unequally based on inequalities that they cannot influence or control in any significant way and for which they therefore cannot be claimed responsible' (Beauchamp 2001, pp. 372-74). For example, 'classification' is already evident as playing a role within sport, whereby athletes are grouped in accordance with their sex, age and body size (Loland and Hoppeler 2012). This ensures that a lightweight boxer for example, is not paired with a heavyweight - as this is clearly unfair, and the outcome inevitable (Loland and Hoppeler 2012). The application of this principle via a *Financial Fair play Policy* may help to reduce the uncertainty of outcome by distributing financial support more evenly amongst teams and athletes (Loland and Hoppeler 2012). This may therefore implement a cap on spending in relation to research and development programmes conducted by teams and organisations within cycling for example, which could work to reduce the opportunities for wealthy teams to 'buy' success through early or even exclusive

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[31] Despite the positive reception of FFP, it is conversely argued that it puts clubs in a difficult situation, incentivising some to invest in new talent, whilst simultaneously limiting others, resulting in overinvestment, generating further financial issues (Preuss et al. 2014).

[32] Before cycling adopts such a regulation, it should look to overcome the issues identified in the above footnote. This could be potentially achieved by increasing the transparency of financial transactions; imposing large sanctions for those who breach the rules; controlling the market in relation to expensive talent; and increasing the existing talent pool in order to reduce the potential for inflated costs due to the scarcity of talent (Preuss et al. 2014).

access to advanced technologies, such as nanotechnology. This would maintain the focus of success on the athlete's efforts and moral character, rather than the strength of the technology in which they use (Morgan 2006). Moreover, this principle could also be employed in order to regulate the cost of nanotechnological cycling equipment, promoting its increased access throughout the sport as a whole. Adopting an approach such as this would help to create a fairer method of application for new and emerging technologies used within the sport, ensuring that cycling remains competitive, particularly during times of increased financial disparity which appears to be evident within cycling at present (Pender 2018).

Additionally, the potential combination of a *Technological Financial Fair Play policy*, and/or the previously discussed policy of standardisation could also work to challenge the concerns relating to the loss of cycling tradition, further limiting any additional breaches of the Lugano Charter. This is because these policies would promote the user friendliness of the bike, ensuring the focus of any given race remains on the efforts of the cyclist, and not the technology (UCI 1996). The policy would also enable greater levels of access to more technologically advanced forms of equipment for those entering the sport; again, helping to improve the credibility of cycling performances, promoting greater levels of equality amongst cyclists.

2.3 Addressing Nanotechnological Manufacturing Concerns

Another disbenefit relating to nanotechnology's application to elite cycling relates to its manufacturing processes, due to potential toxicology concerning human health and on the environment. As previously discussed, if not effectively addressed, this could in turn generate an issue for cycling's image, as if it becomes apparent that 'nano' bikes for example are being produced for elite athletes, and manufactures are aware of the health risks associated with their production but have failed to act in order to reduce such risks - cycling could be seen as an enabler of poor and unsafe manufacturing procedures, negatively impacting its sporting image.

There are many ways in which the UCI[33] could approach disbenefits such as this in order to ensure that any cycling equipment produced that incorporates nanotechnology is done so in safe and ethical manner, protecting the image of cycling. One potential way would be for the UCI and equipment manufactures within the sport to work in a collaborative manner, in order to establish a nanomanufacturing regulatory framework. This could be based on the previously discussed Precautionary Matrix employed in Switzerland, which has been produced in order to safely manage synthetic nanomaterials (Schomberg 2012); developed with the intention of addressing toxicology concerns, and promoting the safe production and trade of goods containing nanomaterials. The implementation of this framework during the manufacturing of nano cycling equipment would therefore offer a more structured approach to recognising the possible risks associated with working with synthetic nanomaterials, such as graphene that is currently being used in the construction of race bike frames (tis 2011). Further, this Matrix would also encourage additional levels of care and self-monitoring for cycling manufactures using nano products, allowing for increased protection in relation to human life and the environment during the manufacturing stages (tis 2011). Hence, if the UCI worked with cycling manufactures in order to apply such a Precautionary Matrix, or something similar to it, it would further promote safe and ethical manufacturing practices, protecting the sport from any potential future health or environmental risks that could pose a risk to its image.

3. Case Study Two - Potential Specific Regulatory Solutions

To summarise, the second of the three case studies centered around nanotechnology's application to an embedded technology, with specific reference to the application of nanobiosensors for the purpose of performance analysis. The following discussion will outline a number of specific regulatory methods in order to address the disbenefits generated through the ethical analysis of this nanotechnological case study. Again, such solutions could then be used to inform the development of a

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[33] Although arguably not a direct concern for the UCI (more a health and safety issue), such concerns in relation to risks associated with the manufacturing of nanotechonlogy for cycling equipment could generate negative connotations for the sport as a whole. A point previously discussed in Chapter five, exemplified by the Nike example.

potential future regulatory framework for nanotechnology's continued use in elite sport.

3.1 The Safe and Ethical Collection, Storage and Use of Athlete's Data

One particular disbenefit relating to the integration of nanobiosensors to elite sport concerns its use to collect an athlete’s biological data, which is highly sensitive and personal information. Consequently creating issues concerning data consent, confidentiality and ownership. It is therefore vital that this issue is effectively regulated in order to protect an athlete’s safety and ongoing wellbeing.

Before considering how to potentially regulate the collection of an athlete’s biological data, specific health governance frameworks must first be put in place in order to determine whether nanobiosensors are safe for human use. The reason for this is at present, biosensors are classed as medical devices and are therefore considered a potential risk to human health, consequently requiring stringent governance procedures (WHO 2019). Due to nanobiosensors being viewed as a more advanced version of the existing biosensor, they too are also likely to require equally as stringent regulation. Moreover, unlike lifestyle trackers (which are also common within elite sport) that are used to promote general wellness, biosensors and subsequent nanobiosensors, are intended for clinical diagnosis (biotricity 2017). Their purpose is therefore to provide biological information via *in vitro* examination of specimens taken from the human body, with the aim of monitoring biological outcomes in order to prevent, treat or alleviate a disease or injury (biotricity 2017; WHO 2019). Consequently, biosensors and more specifically implantable medical biosensors, are regulated in accordance to the Active Implantable Medical Devices Directive 90/385/ECG in order to keep patients safe, with manufactures regularly having to provide clinical trial data in order to prove the safety of these sensors for human application (Gray et al. 2018). Once a sensor does indeed make it through these safety directives and gains market approval, it must then additionally go through post-market surveillance in order to identify any potential limitations/adverse incidents that it may generate (Gray et al. 2018). This is particularly relevant when considering the potential implications of nanobiosensors to elite sport, as these sensors are likely to be implantable, or will require the penetration of skin via nanoneedles in order to collect the biological information (Evans et al. 2016). Further, there is an emerging class of implantable nanosensors under development with the ability to measure a particular analyte *in vivo,* offering the potential to provide the continuous monitoring of a human's biological function (Ruckh, T et al. 2014). Consequently, much like current biosensors, nanobiosensors are very likely to require specific stringent medical regulation in order to continue to protect the wellbeing of the user. To achieve this, sporting bodies could employ and adapt into their own technological regulations the recently revised governance framework for medical devices written by the European Union, known as the European Medical Devices Regulation (BSI 2019). This framework is an updated version of the previously mentioned Implantable Medical Devices Directive 90/385/ECG and Medical Devices Directive (93/42/EEC), and provides increased levels of scrutiny in relation to technical documentation; addressing concerns relating to the assessment of product safety and performance by placing stricter requirements on clinical evaluation and post-market checks, increasing traceability of devices through the supply chain (BSI 2019).

Once these sensors have successfully gone through a safety directive such as this, and have been declared safe for human use, then an initial trial study should be conducted in order to determine the suitability of nanobiosensors for the role of collecting biological data for performance analysis purposes in sport. Yet due to these trials requiring human subjects (in this case athletes), additional regulatory protocols would be required in order to oversee this process, continuing to promote high standards of safety and ethical governance. In order to achieve this, the following written protocols could be adhered to in order to inform the participant of what is due to happen during this trial period:

1. *The purpose of the study.*
2. *The drug, device, agent, biological substance, practice, or other intervention that is being tested.*
3. *The risks and benefits of the interventions being tested and the procedures being used.*
4. *The criteria for subject inclusion and exclusion.*
5. *The methods of experimentation.*
6. *The duration of the study.*
7. *The producers for collecting and analyzing the data – All of which must be completed via voluntary consent* (Maschke 2009).

Such protocols were originally devised in the Twentieth Century in order to promote good ethical research when conducting studies with humans, ensuring that all participates understand the purpose of the trial, allowing them to make more informed choices throughout (Maschke 2009). Therefore, by following an ethical protocol such as this will not only promote good ethical practice, it will also ensure that all participating athletes feel more a part of the process, and informed in relation to the purpose and goals of the study. Consequently, making them feel more in control of the process, promoting true autonomous decision-making. To further support such a protocol, a multi-disciplined ethical board could also be established (which is a legal requirement in America, and a requirement for all research such as this conducted in accordance to the Declaration of Helsinki) to oversee any trials of this nature, ensuring independent adjudication along with impartial decision-making. Furthermore, such trials must have social and scientific value in accordance to the Nuremberg Codes and Declaration of Helsinki (Maschke 2009). Thus, if it becomes clear that using nanobiosensors for performance analysis purposes is not actually effective, or the study goes beyond what was originally laid out in the initial protocols, then the trial should be stopped, and the process reviewed in order to make improvements for any further trials that may be conducted in the future (Maschke 2009).

Once these sensors have successfully passed the initial safety directives and study trial periods, it will prove them as not only safe for human use, but an effective method of gathering data for performance analysis purposes. Specific regulation may then be established in order to govern how an athlete's biological data could be collected, stored and used within elite sport. This process could start by integrating the application and use of nanobiosensors for performance analysis purposes into existing Collective Bargaining Agreements already used in some sports such as basketball (2017). This agreement is presently used in order to protect the rights of basketball players, and have recently been extended to address and regulate the use of wearable tracking sensors; outlining what a team can and cannot do in relation to the data they collect from a player at any given time. For example, the agreement stipulates that the wearing of a tracking device for performance analysis purposes is voluntary, and before a team can request for an athlete to wear one, they must provide written confirmation explaining the following information; the purpose of the device, what the device will be measuring, and what the benefits for the player will be through the use of such a device to collect data (NBA 2017). It also argues that the player will have full access to the data collected, and that members of the team's staff may only have access to the data for a limited period whilst conducting performance analysis related tasks in order to further support a players performance and levels of safety (NBA 2017). This agreement therefore works to ensure that an athlete remains informed in regard to how their data will be collected and used, protecting them from potential data misuse. The agreement states that any data collected can only be used for performance analysis purposes, and for example shouldn't be used in contract negotiations, which could result in a team being fined (NBA 2017; Osborne and Cunningham 2017). The use of nanobiosensors could be built into these Collective Bargaining Agreements, and their application universally expanded to all sports that wish to make use of such sensors for the purpose of performance analysis.

After considering these agreements, two additions could be made in order to further protect an athlete's rights in relation to the use of this technology to collect their biological data. The first of which relates to the financial fines in place for any club that misuses an athlete's data, which should be conducted on a case-by-case basis due to the disparity of wealth between some clubs and organisations. Consequently, the setting of universal fines (as seen in the past and present) may be a significant deterrence for some but not for others, who may feel that the fine is worth paying if it allows them to renegotiate an athlete's contract for example. Therefore, an effective financial deterrent must be established in order to reduce the potential willingness of financial risk by teams in order to exploit an athlete's data in a potentially negative manner. The second is that Collective Bargaining Agreements should also incorporate third party uses, something that is currently not included within the NBA's Collective Bargaining Agreements (Osborne and Cunningham 2017). This will further promote an athlete's data rights, allowing them to control how their personal data is used outside of their given sport, such as in the gaming and betting industries for example. Further, limits in relation to how these sensors are used in an athlete's private life could also be established via the agreement. This is because it would be reasonable to foresee the 24/7 cycle of data collection to exploit nanobiosensor potential; heightened during peak competition times, but gathering important non-performance data even at rest. Therefore, it may become highly invasive into an athlete's life, and consideration must be made in relation to how this could be effectively controlled.

Once agreements are in place, systems relating to data collection/storage, consent and security can then be established. Data collection and storage may be explored via the use of a model similar to the proposed NHS Personalised Health and Care 2020 framework (HMG 2014). A performance analysis digital platform may be established, allowing for data to be collected wirelessly via nanobiosensors and stored on a central database overseen by an independent regulatory body (HMG 2014). This process would therefore encourage impartiality in relation to data collection; removing issues surrounding data ownership, and reducing the potential for corruption. Further, in regard to issues concerning consent, regulatory bodies could address this in a similar manner as the NHS with its implementation of the UK's NHS Act of 2006, Data Protection Act, and Human Rights Act in medicine[34] (NHS England 2012). An athlete could sign legal documentation to ensure that their biological data is protected from misuse, stored correctly, and used only when authorised, ensuring that it is not accessed against their will, and potentially used in a detrimental way. Moreover, these acts could in turn be built into new contractual agreements in preparation for the use of these sensors, such as Collective Bargaining Agreements, ensuring the continual protection of athlete's rights. A role-based access control could be used to protect any data stored, as this decreases the complexity and

[34] A note must be made that this analysis is UK centric, and other frameworks similar to these use in other countries may also be applicable.

rather high cost of securing a large data storage network (Meingast et al. 2006). Again, these acts and policies are often used in the health care service in order to protect patient data and ensure confidentiality, avoiding the potential for eavesdropping or data skimming. For example, an encryption service could be based on technology employed by those such as TinySec, which has been purposefully created with sensor networks in mind, and is able to both encrypt and authenticate data for additional protection (Meingast et al. 2006). A team of independent adjudicators could also be used to apply, monitor, and ensure the correct implementation of nanobiosensors to deter its potential misuse and corruption within elite sport.

Finally, once these regulatory systems have been established, it is essential that educational courses are also made available to athletes in order to inform them fully with regards to the role and purpose of using nanobiosensors for performance analysis. This will promote an athlete's knowledge, ensuring that they are informed in relation to how their biological data will be collected, stored and used; therefore fostering greater levels of trust and transparency (ST 2017). Only once an athlete has completed each of the modules can they make an informed decision in relation to whether they wish to opt in or out of wearing said sensors for performance analysis purposes. Therefore, until the course has been completed, a club/organisation should not be able to force an athlete into wearing sensor technology such as this.

3.2 Challenging Corruption

The application and use of nanobiosensors for performance analysis purposes raises additional concerns with relation to the increased potential for corruption within the sport. This could include data hacking in order to access an athlete's biological data with the aim of gaining a competitive advantage; the use of data in order to potentially sway contract negotiations; or the potential extortion of an athlete by threatening to release negative health information. Each of which may have a damaging effect to the athlete, both in terms of their professional and personal life (Evans et al. 2016).

There are many ways in which this issue could be addressed in order to reduce the potential of corruption. One of which, is via the implementation of an effective security network in order to prevent data hacks, alongside the establishment of independent bodies in order to oversee sensor use, preventing the potential introduction of 'rogue sensors' into the network system. Furthermore, the establishment of Collective Bargaining Agreements would also prevent biological data from being used to manipulate contract negotiations, for example.

Taking action such as this would limit the potential for an athlete’s biological data to be put at risk, and corruption occurring in the first place. Additionally, the establishment of an independent data collection body as mentioned above, would further ensure the safe and ethical collection/use of an athlete’s data, taking the control out of the hands of a team, organisation or even betting company; again reducing opportunities for data manipulation. Further, independent bodies could be regularly subject to their own internal monitoring systems and security checks in order to further ensure the effective collection, storage, and use of an athlete’s biological data.

3.3 Limiting the Deskilling of an Athlete

Another disbenefit relates to the potential that nanobiosensors may have in relation to the deskilling an athlete, through increased reliance on sensor technology in order to regulate their levels of performance and health, challenging their need to self regulate and monitor (James, 2010; Magdalinksi, 2008; Miah, 2006).

Possible deskilling such as this could be avoided by limiting when athletes and coaches are able to use this technology for performance analysis purposes. This could for example involve limiting access to the sensors during training sessions; meaning that only data collected during this time period may be analysed in order to improve an athlete’s levels of performance in preparation for a competition. This would allow for progression to be made without removing the need for the athlete to self regulate, as they would still be responsible for their own maintenance beyond these sessions. Consequently, the onus would still be on the athlete and coaches to effectively analyse this data in order to propose dietary changes and bespoke training methods, without removing the need for an athlete to self-regulate.

Moreover, such limitations should also be extended to competition time also, as this is when an athlete is required to demonstrate their hard work and skill against another equally matched competitor. Consequently, if nanobiosensors were to be used during this time, it could in fact challenge an athlete's requirement to self manage. For example, if nanobiosensors were used in a football match, they could be used to monitor a player's lactate levels; thus, simply allowing teams to simply substitute players when very low in energy and high in lactate, much like the ease of doing so in a computer game. The player would therefore no longer have to self-regulate, but simply wait for instruction from the sidelines; not only working to deskill the player, but also devalue their performance in the eyes of the spectator (James 2010). Operating these limitations would therefore ensure that the athlete remains in control of their own performance.

One exception to the limitations posed above may be that athletes are required to wear these sensors when competing in order to further safeguard as a health and safety control measure. Medical staff could be given access to the live data feeds in order to monitor them to reduce risk such as exhaustion or cardiac problems as witnessed previously in elite sport (Ferguson 2012). Medical staff employed should be independent of any club, organisation or team, in order to promote neutrality; ensuring that those who may have a vested interest in a particular competitive outcome do not sway their medical decisions.

4. Case Study Three - Future Regulatory Solutions

To summarise, the third and final case study focused on nanotechnological application to an embedded technology, but this time with specific reference to its third party application for horse race betting. The following discussion will therefore outline a number of specific regulatory methods in order to address the disbenefits generated through ethical analysis of this nanotechnological case study. The solutions posed could then be used to inform the development of a potential future regulatory framework for nanotechnology's continued use in elite sport.

4.1 Challenging Data Use and Fairness Concerns

The disbenefit relating to data use and fairness of nanobiosensors for the purpose of horse race betting raises similar concerns to those generated in case study two. The potential misuse of data in relation to horse racing could be damaging not only to the owner, but equally for the rider and trainer. Further, unequal access could offer an unfair advantage to those who do have access to this technology, not only in relation to developing their own performance, but also via increased betting revenues. It is therefore essential that data collected through nanobiosensors is done so in an acceptable manner for all stakeholders, with existing means of regulation being adapted in order to govern its use, such as the Data Protection Act in Gambling. This seeks to regulate key betting data information such as third-party use and consent/compliance issues, in order to promote fair use of data (Gambling Commission 2011a; Gambling Commission 2018b). Moreover, the direct application of this act in support of the effective governance of this technology would work to put the onus of responsibility in terms of how the data is utilised back on the betting companies. Ensuring that they understand the risks of implementing the technology, and take accountability for any potential misuse of information (Gambling Commission 2018). Further, an independent body could also be established in order to collect the data streamed via the nanobiosensors for betting purposes, ensuring neutrality, and again reducing the potential for arguments in relation to data ownership and potential damaging misuse of such data. This body should monitor data streams in order to prevent risk, such as potential odds fixing, or any other forms of corruption.

As already suggested in this chapter, a Collective Bargaining Agreement should be established between key stakeholders, in this case the owners, trainers, jockeys and betting companies (and racetracks/BHA if required), ensuring that all parties agree as to how this data will be collected and used for betting purposes. Thus, promoting a mutual working consensus between all relevant stakeholders. Onboarding an approach such as this could prove highly positive for the sport, illustrating a conscious effort to progressively move forward in areas such as animal welfare. This may in turn help to bring more spectators back to the horse racing, which could promote and refresh betting revenue streams for the sport as a whole.

Furthermore, in order to address the concerns that relate to equality, a policy of standardisation could also be established, promoting equal access to this sensor technology (Loland 2009). If it were determined that nanobiosensors were to be used for betting purposes then the application of a universal betting nanobiosensor should be applied by an independent body prior to a race in order to promote fairness, safety, and anti-corruption.

4.2 Addressing Potential Corruption and Addiction Issues

Increased levels of corruption and the further exacerbation of addiction levels that the use of nanobiosensors may generate via the domain of betting is another disbenefit concerned around the case study. It is therefore essential that flexible regulation be implemented in order to protect against potential corruption and foul play when using this technology for betting purposes. This could be achieved through the modification of existing betting regulatory frameworks, whilst also adapting others used in sports such as football's UEFA (2012) Financial Fair Play framework, and betting fraud detection system policies. The adaptions of such policies in order to encompass the use of nanobiosensors for betting purposes in horse racing could also ensure that these sensors are integrated in a fair and ethical manner, adding an additional layer of protection against any potential misuse of this technology.

It is also essential that effective security systems are established in a similar manner as previously discussed in case study two, as betting data will be transmitted across a wireless network open to the possibility of data theft. Hence, there would be a significant need for an effective security network to be developed in order to ensure the confidentiality of this data, and implement preventative anti corruption measures (Evans et al. 2016). This could again be modeled on existing systems, such as the aforementioned wireless sensor security network solutions created by those such as TinySec, LSec, LISA and MiniSec, all of which have been developed to offer data protection and encryption services for wireless sensor technology for additional protection (Dener 2014). In addition, the handling of such technology, much like it was suggested in case study two, could be dealt with by an independent third party company, who could apply and monitor the sensors in an ethically justifiable manner in order to deter any potential misuse which could result in corruption.

A possible way forward in order to address concerns relating to addiction may be to regulate the number of bets that can be placed when using this technology. This would limit access to utilising the technology as a method of betting, in turn helping to reduce the potential of addiction, whilst seeking to restrain issues for those with existing betting addictions. Educational courses should also be made available in order to inform the public of the purpose, role and risks (such as addiction) that betting via the use of nanobiosensors may present; enabling better-informed bets when using data ascertained via this technology. Gambling support companies should also be integrated in tandem with educational courses such as these in order to support those who may have or may be developing a potential gambling addiction; offering preventative measures for those developing an addiction from the offset, or seeking to reduce the impact on those already suffering. There are a number of companies available, including GamCare (n.d.) for example, who offer youth outreach programs, work within the criminal justice system, and also provide safer gambling training courses.

4.3 Preserving the Spirit of Betting

The emergence of modern betting technology has become a double-edged sword for horse racing. The development of Wi-Fi active tracks, along with the rise of modern sensor technology has on one hand helped to rejuvenate a failing betting industry, bringing new interest to the sport by offering a variety of ways in which a bet may be placed within horse racing. On the other hand, it has also presented a challenge to the sport, as technologies such as future nanobiosensors could be detrimental to the spirit/nature of betting. Consequently, the data generated via the use of nanobiosensors could be counter productive for horse race betting, making the process more formulaic (and dull), supporting a potentially negative form of technological determinism, again as discussed previously (MacKenzie and Wajcman 1999). Thus, eliminating the very reason why many do bet; to apply one's intuition and 'luck of the game' - which is what often makes it so exciting.

It is therefore essential to maintain a balance between old and new in order to preserve the spirit of betting within horse racing; whilst allowing it to embrace new technologies in order to further improve betting practices as we move to the future. To achieve this, limitations could be set as to when nanobisensors are used for betting purposes, for example in general races which are often poorly attended in the UK, nanobiosensor technology could be deployed (Baxter 2018). This could help to increase public interest in these races, which in turn could generate increased betting revenues. In addition, the use of this technology could also work to create better odds for these races, luring more people in and again increasing the potential for financial return. Bookies may also be encouraged at this time to receive bets via the Internet, maintaining their role within this process, yet with a modern twist. Instead of taking a phone call from a gambler or receiving a bet at the track, they could instead direct them to a website where bets will be recorded, tracked and totaled, generating a far more user friendly interaction between both the punter and bookie, whilst ensuring that the traditions of the bookie remain relevant (Borden 2012). This could include betting data gained through the use of nanobiosensors, which would in turn seek to embrace modern technology within the sport without it having to lose its vital traditions.

Conversely, during horse racing's more significant meets such as the Grand National, the use of nanobiosensors could be limited to data collection in order to promote equine welfare only. Thus, when a horse is at risk or under great strain, a rider could be told to stop, removing him/herself from the race, whilst ensuring that the horse is protected from any permanent damage. An approach such as this would again be seen as positive for horse racing in two ways; firstly, it would reduce the chances of technological determinism in relation to betting during these races, as the additional biological data would not be available to the public to bet with. Instead the gambler would have to use traditional methods in order to place their bets, which will continue to maintain the excitement of the process during the bigger festivals. Secondly, it will go some way to appeasing those who do not attend horse racing on animal welfare grounds; and so by taking this approach, it is possible to maintain a balance between the betting traditions so highly valued within horse racing, as well as the emergence of new betting technologies without the sport having to become predictable.

5. Conclusion

The purpose of this chapter was to provide specific regulatory methods in order to inform a potential future nanotechnological governance framework; conducted through careful consideration of the disbenefits raised by each of the case studies ethically analysed during this work. This in turn generated a range of potential regulatory outcomes that could be used to effectively govern each of these disbenefits. In relation to those produced by case study one, methods of regulation presented included examples such as standardisation, fair and ethical equipment manufacturing, and material financial fair play methods (Slater 2017; Meingast et al. 2006; CIENTIFICA n.d.). In regard to case study two, methods of regulation presented included examples such as the introduction of the data protection act, the development of an effective security network, and the establishment of collective bargaining agreements for the application and use of nanobiosensors amongst athletes (Evans et al. 2016). Finally, in relation to the disbenefits raised in case study three, methods of regulation presented include examples such as the adaption of existing betting regulations, the development of an effective data protection system run by a third party, security data networks for the reduction of potential corruption, and limitations of use in order to protect the spirit of betting (Evans et al. 2016, UEFA 2015; Dener 2014).

Now that a range of regulatory actions have been established in order to inform a potential specific nanotechnological governance framework, the next chapter will conclude this body of work, offering a summary of the research findings; reviewing the problem question along with its aims and objectives; and finally considering its current and future implications in relation to the fields of sports engineering and ethics.

Chapter 11 - Conclusion

1. Introduction

The present research is an ethical analysis of nanotechnology's potential application to elite sport. The aim of which, was to determine the potential benefits and disbenefits this technology may present elite sport, and to determine how to effectively govern its continued use and application within the field. A consequentialist analysis of three nanotechnological case studies was presented, which identified a number of benefits/disbenefits in relation to each application. The aim of this was to address the existing knowledge gap that surrounds nanotechnology's use within sports engineering, and its potential ethical impact on elite sport. The argument and evidence demonstrated that despite the obvious benefits nanotechnology offers both the athlete and sporting system as a whole, there are also a number of disbenefits, which due to the infancy of the technology, cannot simply be ignored in favour of progress. These issues must be addressed, and consequently an argument was presented for nanotechnology's initial integration of governance by a weak version of the PP. This would inform and allow time for a more specific regulatory framework to be established, ensuring that both the athlete and sporting system as a whole remains protected, as nanotechnology continues to evolve and develop thereafter.

This chapter concludes the research by reviewing the thesis aims, objectives and initial research question, followed by a summary of each of the chapters, where key findings will be outlined and links to the aims, objectives and the research question will be established to demonstrate how each have been met. Finally, the latter sections of this chapter will consider the present and future implications of this research for elite sport, outlining how it has contributed to existing knowledge in relation to sports engineering and ethics, as well as offering ways in which further research could be conducted in order to inform future work.

2. Thesis Review

Chapter one offered an overview of the emergence of elite sport, along with its accompanying modern philosophy centered on the importance of winning. Athletes, teams and coaches are continually on the look out for new and innovative ways in which to improve their levels of performance, and therefore their chances of winning in a given competition - an area of particular dominance is that of sports engineering.

This resulted in the recognition of an increasing number of new and emerging technologies currently implemented into elite sport. One example, the focal point of this research, is nanotechnology. The integration of this technology is already evident in its implementation within sporting equipment, with engineers exploiting its property benefits in order to generate improved levels of performance and safety. However, despite its ever-increasing presence in the domain of elite sport, there exists a knowledge gap in relation to the ethical impacts it may have. A potentially transformative technology such as this could impact the integrity of sport if not effectively considered, and therefore further ethical examination was required. To address this problem, the following research question was posed:

What are the potential benefits and disbenefits of nanotechnology's integration into elite sport and does it require additional governance?

In order to answer this question, two research aims were presented:

1. *To consider the potential ethical impact nanotechnology may have on elite sport.*
2. *To propose regulatory solutions in order to promote good governance practices in relation to nanotechnology's initial and potential future integration into elite sport.*

These aims were broken down further into a set of four objectives, which as a re-cap are as follows:

1. *To review the impact sports engineering has already had on elite sport, by considering existing academic literature in order to establish key background information on the topic of sports engineering.*

2. *To examine how and why sports engineers are looking to intergrate nanotechnology into equipment used at the elite level.*

3. *To conduct a review of nanotechnological case studies in order to determine its potential impact as a technology on elite sport.*

4. *To examine and ethically evaluate the results of this review in order to determine solutions for its effective governance within elite sport.*

5. *To recommend regulatory solutions based on the ethical evaluation conducted in the previous aim, promoting effective governance practices for nanotechnology's use in elite sport.*

The completion of the first objective took place in chapter two, where a foundation of knowledge in relation to sports engineering was established. This was carried out by consideration of how sports' engineering has emerged over time, alongside for example, its progression as a field of study via the integration of material science (Taha 2013). This chapter also identified two key terms which were essential to the latter chapters of this research; the first being 'enabling technologies', referring to equipment that an athlete uses to compete with; and 'embedded technologies', referring to those technologies that are used behind the scenes in order to improve performance levels by methods of performance analysis (Bhania 2012). Both of which are considered to be essential tools to modern athletic success, assisting athletes in reaching new levels of performance. Once this was outlined, a review of the available academic literature in relation to the ethical impact of sports engineering on elite sport was conducted. The findings demonstrated mixed opinion, with some holding that its emergence and development as a field since the end of the 19th century has offered sport a number of significant benefits, such as improved levels of performance, increased safety for athletes, and the promotion of sporting innovations (Taha 2013; James 2010). Thus, cementing its importance as an essential element of modern elite sport, not only for the athlete's individual progression, but also for the sporting system as a whole. On the contrary, several scholars challenged this view point, arguing that despite the benefits, sports engineering has also generated a number of disbenefits, such as those relating to equality/fairness, deskilling, and challenges to the spirit of sport (James 2010). Furthermore, in some cases it was argued that sports engineering actually posed a threat to the integrity of a given sporting competition, undermining its purpose and values. This can have a profound impact on the various stakeholders and communities within sport, as all want to compete within a fair and equal playing field. By doing so, it enables the winner of a competition to be the one who has earned it through their own strengths and not that of a particular technology. If this is the case, it can undermine the purpose of sport, as spectators may value athletic success less and athletes/coaches no longer see the point in competing if it is likely that they may never win due to others possessing a technological advantage (James 2010).

Consequently, it was clear that there existed extensive debate in relation to the role of sports engineering, and the accompanying technologies it has produced have had (and are still having) on elite sport. Yet despite an extensive review of the literature, it soon became apparent that there was a clear lack of academic research in relation to the potential ethical impact nanotechnology may have on elite sport, despite it already being integrated within the domain. This exposed a problematic knowledge gap, which was argued that if not effectively considered, could put the integrity of elite sport at risk. To address this, it was decided that the remainder of the research would be dedicated to addressing the issue, in order to determine the potential impact this technology may have on elite sport, and to determine how best to move forward with its implementation.

Before considering the ethical benefits/disbenefits of this technology's use within elite sport, it was essential for the second objective to be addressed. This enabled an understanding as to why sports engineers are increasingly turning to nanotechnology in order to improve existing sporting equipment, whilst also outlining the methods in which engineers are applying this technology as a way of improving athletic performance and safety levels. Chapter three therefore began by offering two key definitions; the first of which was 'nanotechnology', defined as a science, engineering and a technology that is conducted at the nanoscale - 1 nanometer and 100 nanometers in size (EPA 2007; Boysen 2015; NNI 2019, para.1). The second being 'nanomaterials', defined as a material that contains particles, in an unbound state or as an aggregate, where 50% or more of the particles under the number size have one or more external dimensions in the size range of 1nm-100nm (EC 2011). Thereafter followed a brief historical overview of nanotechnology's emergence as a field, a term first coined in 1974 by Norio Taniguchi in his paper *In the Basic Concept of "Nanotechnology".* Later propelled by bodies of work by Drexler, Kroto, Smalley and Curl (Hulla et al. 2015; Drexler 1987; Allhoff et al. 2010).

The current methods of applying nanotechnology were then presented, identifying its advantageous properties such as it's small size, increased strength, excellent ability to disperse heat and conduct electricity (NNIN 2006), as major factors when identifying the incentive for sports engineers when integrating the technology into sporting equipment. These advanced properties have thus made it an ideal construction material for its use in elite sporting equipment, hence why nanotechnology has already found its place within sporting equipment such as the Wilson nCode Tennis racquets, CNTS golf clubs, and 'nano' treated sports wear and nano-films used in sporting venues (NNIN 2006; Smith 2018; Nano 2017; nanocyl 2007; Harifi and Montazer 2015). Moreover, as our understanding of the technology continues to improve alongside design and construction techniques, it became apparent that nanotechnology is only likely to increase its prominence within elite sport for years to come. However, it was argued that the knowledge gap surrounding its ethical impact on elite sport had to be addressed before its full-scale integration, ensuring that the integrity and nature of sport remained protected.

Establishing an appropriate methodology was essential in determining the potential ethical impact of nanotechnology on elite sport; outlined in chapter four, where several nanotechnological case studies were presented, each selected on the grounds of originality, their ability to span the key boundaries of sports engineering, and the current lack of regulation within their given sports. The first of the case studies considered nanotechnology's application to an enabling technology, with specific reference to the race bike in elite cycling. The second considered nanotechnology's application to embedded technology, via the use nanobiosensors for performance analysis purposes. And finally the third considered nanotechnology's application to sports betting, specifically nanobiosensor's implementation within horserace betting. Yet, despite the benefits of such case studies, limitations were also identified in relation to their selection for analysis in this thesis. These included the limited range of case studies; the difficulty in predicting potential outcomes, particularly in relation to future technologies such as those referred to in case study two and three; and the potential lack of in-depth analysis, where some may argue that it would be better to focus on one aspect of sports engineering at any one time. Despite these limitations, it was felt that the selection of these case studies would allow for greater insight into how this technology may impact the world of sports engineering as a whole, and not just a single element of it; which has been proposed as an avenue for further research.

Once the case studies were outlined, an ethical analysis framework was adapted for the subject matter at hand. Prior to this, clarity was needed in relation to which ethical approach should be adopted. Due to the nature of this work, and the need to apply a technology to real life scenarios in order to establish formative knowledge in which to ethically consider, a hybrid approach was developed. There were a number of reasons for this decision, but one key reason was due to the regularity in which applied ethical approaches were being used within the fields of sports engineering (and engineering and technology more generally) in order to solve such ethical issues arising in that domain. This is particularly pertinent when the available knowledge/rules/governance in relation to a technology was limited or indeed lacking. Enabling normative evidence to be gathered via real life application, can usefully inform key ethical decisions (Davis and Yadav 2014). This was relevant to a consideration of nanotechnology's initial application to elite sport. Due to the limited knowledge available in relation to its potential ethical impact, and the current lack of governance that surrounds its use as a body of technology within elite sport, embracing an applied approach enabled this knowledge provisionally to be established via the case studies, which in turn would inform ethical debate and allow for decisions to be made in relation to nanotechnology's regulation within a given sport.

Once an applied ethical approach was selected as the model of 'best fit' for this given research. Before its application, it was first essential to establish normative evidence in which to inform the applied ethical approach. To achieve this, a generalised consequentialist framework was selected in order to provide the benefits and disbenefits appropriately. There were a number of reasons for the selection of this theory, such as its ability to promote justice/happiness, its plausibility and universality as an approach, and its lack of complexity; not requiring a complex decision making framework in order to reach a decision outcome (Grisez 1978; Stubbs 1981; Regis 2019; McNaughton and Piers 1998; Vallentyne 1987; Bentham 1789; Mill 1859). Further, it was outlined that the aim of the research was not to conduct a fundamental philosophical scrutiny of any underling ethical theory, but rather to gather normative evidence in relation to how nanotechnology may ethically impact sport in order to drive debate. The role of consequentialist thinking within this work was to act as an initial frame, highlighting the applied ethical issues generated by the review of the case studies. This in turn then allowed for and informed the ethical debate in relation to the benefits and disbenefits nanotechnology presented elite sport via each of the case studies. But, in order to promote ethical integrity, the limitations of a consequentialist approach were also offered. These included its inability as a theory to predict all future consequences; its lack of potential impartiality; and the threat it could represent to an individual's rights (Baker 2016; Frey 1984; Smart and Williams 1973; Stubbs 1981). Yet despite such limitations, a further argument was put forward for its continued application as a 'best fit' in relation to conducting an analysis of the case studies. The chapter concluded by highlighting that although this work represented a predominately consequentialist approach, it did not reject outright key deontological concepts generated by the application and use of sports engineering and technology within sport, for example, in terms of justice and equality. It was therefore argued that the arguments must embrace such concepts when deemed useful in aiding and further informing key ethical debate, enabling the later half of the problem question to be addressed in terms of the morality/regulation of using nanotechnology within elite sport. Consequently, it was argued that this work would embrace a 'hybrid' applied ethical framework, drawing similarities to other ethical approaches within other fields of research, such as principlism within bioethics.

After establishing the ethical framework, chapters five, six and seven addressed aim three of this research, the ethical analysis of the case studies. These chapters offered an extensive consequentialist review, firstly by providing key background information to provide context, as well as a consideration of the potential ethical impacts that each may present in terms of benefits/disbenefits. The findings of which generated a variety of consequentialist outcomes. The following tables summarise the key findings in relation to each of the case studies:

Table 2: The benefits and disbenefits of using nanotechnology in elite cycling

Benefits for the Athlete	Benefits for the Sport	Disbenefits for the Athlete	Disbenefits for the Sport
Improved Levels of Performance	**Increased Spectator Engagement**	**The Best Athlete May Not Win**	**A Challenge to the Spirit of Cycling**
Increased Levels of Safety	**New Financial Opportunities**	**Financial Fair Play and Equal Access**	**Manufacturing Concerns**

Table 3: The benefits and disbenefits of using nanobiosensors for performance analysis

Benefits for the athlete	Benefits for the system	Disbenefits for the athlete	Disbenefits for the system
Increased Performance Data	**Improved Safety in Sport**	**Athlete Consent, Confidentiality and Data Ownership**	**Unfair Competition in Sport - 'Technology Doping'**
Increased Value for the Athlete	**Deterrence to Cheating**	**Deskilling of an Athlete**	**Facilitation of Corruption**

Table 4: The benefits and disbenefits of using nanobiosensors for horse race betting

Benefits of Using Nanobiosensors for Horse Race Betting	Disbenefits of Using Nanobiosensors for Horse Race Betting
New Forms of Betting	**Concerns Over Data Use/Interpretation and Fairness**
Increased Betting Immersion Through Technological Layering	**Increased Risk of Corruption and Addiction**
A Multipurpose Application	**Counter Productive to the Spirit of Betting**

This ethical analysis of the case studies addressed objective three, along with the first element of the research question.

Once such ethical discussion had been conducted and essential evidence established; chapter eight (completing objective four) proceeded by conducting an applied ethical analysis of the results. The main findings of which revealed that it would be challenging to describe the use of nanotechnology, particularly in reference to the case studies, as forms of cheating, as they are not in breach of any existing regulations or rules. Yet this did not rule them out from being considered modes of technological doping. Therefore, in order to determine whether they could be classed (either as an assistive technology or a form of technology doping) as such, the IPC[35] (WPA 2018) equipment judgment framework was applied to each of the case studies, which proposed the following assessment criteria:

> *1. Safety - the equipment must be safe for competitors, officials, spectators and the environment.*
>
> *2. Fairness - the athlete must not receive an unfair advantage against the spirit of the event they are contesting.*
>
> *3. Universality - the equipment must be reasonably commercially available to all.*
>
> *4. Physical prowess - human performance is the critical endeavour, not the impact of the technology and equipment.*

The ethical analysis found that in almost all cases, each of the nanotechnological examples met the criteria established in the assessment framework. Consequently, each of the 'nano' case study examples discussed in this work can only be considered to be assistive technologies at present, rather than forms of technology doping. Yet despite this, concerns were also raised, particularly in relation to the nanotechnological examples ability to further micro-manage performances; exacerbate fairness issues; and generate toxicology concerns for both human life and the environment. In addition, due to its infancy as a technology, its potential long-term impacts are still unknown, and therefore what is considered as an assistive technology now, could in the future be classed as a form of technology doping. This

[35] In order to remind the reader, the IPC (WPA 2018) framework was selected due to Parathletics reliance on technology in order for each sport to be conducted. Consequently, the IPC framework is specifically and effectively constructed in order to address concerns relating to technology doping, as drawing a line between what is considered an assistive technology and a form of technology doping is essential in maintaining the ethics and integrity of Para sports (Weston 2016b).

has already been evident in other sports, such as the aforementioned Speedo LZR Racersuit (Dorey 2012). Yet despite this, it was argued that actions in the form of bans would be counterproductive, and often fail to resolve such issues.

Therefore, it was clear that despite the benefits each of the case study examples generated, they also raised a number of early warning signs for elite sport that must be addressed. These findings informed further discussions in chapter nine, where regulatory actions were considered in order to limit the potential of these nanotechnologies becoming forms of technology doping. This resulted in an argument being presented for the application of precautionary measures in order to safely govern their initial integration into elite sport. To achieve this, it was suggested that a specific nanotechnological regulatory framework be established in order to address specific nanotechnology associated risks within sport. However due to nanotechnology's infancy, and the time it would take in order to generate such a framework, there would likely be a regulatory gap between its establishment and the current integration of nanotechnological sporting equipment to elite sport. In order to bridge this regulatory gap, it was additionally argued that a weak version of the PP embedded into an ethical analytical tool should be applied (addressing the first section of objective four, and in turn the second half of the problem question). An approach such as this would promote a far more controlled and monitored integration of nanotechnology into elite sport, whilst additionally allowing for the benefits of this technology to be exploited. This also generated a two step process, where firstly a piece of nanotechnological sporting equipment is initially regulated via an ethical analytical tool underpinned by a weak version of the PP; which enables for safe/ethical monitoring to take place in order for more specific regulation to be generated (and then be used to inform a specific 'nano' regulatory framework) if required. The chapter concluded by arguing that the use of such a weak version of the PP should not be seen as a long-term governance solution for the regulation of nanotechnology within elite sport. Rather, sporting bodies should use the time that this initial (regulated) integration period offers in order to determine the specific risks that nanotechnology may present and establish an informed regulatory framework in order to specifically govern the disbenefits this technology may generate going into the future. This would further promote improved governance practices, and effectively prepare elite sport for any potential risks that nanotechnology may present as its application continues to expand moving forward.

Chapter ten presented a number of specific regulatory actions in order to specifically regulate the risks associated with the case studies discussed in this work. These governance actions arguably could be used in order to inform the creation of a future 'nano' specific governance framework for elite sport in the future. In relation to case study one, examples included a potential standardization policy, regulation of materials, a financial fair play policy and the application of a precautionary matrix for the manufacturing of cycling equipment using nanotechnology (Schomberg 2012; Loland 2002). This was followed by case study two, with examples including collective bargaining agreements, the limitation of nanobiosensors to training uses only, standardisation of sensors, and the implementation of an effective security network in order to protect athlete data (Loland 2002; Evans et al. 2016; NBA 2017). Finally the third case study, where examples included the adaption of the existing Data Protection Act, Collective Bargaining Agreements, Financial Fair Play Frameworks, limitations of use and an effective security network system such as those developed by TinySec, LSec, LISA and MiniSec for example (Gambling Commission 2011a; Gambling Commission 2018b; UEFA 2015, Evans et al. 2016; Dener 2014). By taking such actions, it was reasoned that nanotechnology could be integrated into elite sport in a safe and ethical manner, ensuring that the integrity of sport remains protected at all times. This chapter consequently addressed the final objective, further completing the aims of this body of work, and therefore fully informing the overall research question.

3. Implications of this Research

There are three main implications of this research, each of which demonstrate how this specific body of work has added to existing knowledge in relation to the fields of sports engineering and ethics in an original manner. The first of which concerns the main purpose of this research, which was to identify the potential ethical impacts nanotechnology may have on elite sport, as prior to this, there was very limited ethical research conducted in relation to this issue. This work has therefore outlined a consequentialist analysis of three nanotechnological case studies; taking into consideration the potential benefits/disbenfits this technology may present elite sport. Consequently, working to address and inform the existing knowledge gap that surrounds nanotechnology's application to elite sport. Moreover, this work could also be seen to be timely, given that nanotechnology is still in its infancy in relation to sports engineering, and its application to elite sport. Hence, this research provides a vital ethical discussion and much needed evidence in relation to how this technology may impact the individual athlete, sporting system and sports betting industry, which may inspire sporting bodies to conduct further research into nanotechnology's potential application within their own sports. This broadens the available research in relation to this issue, and adds to existing academic research in order to further bridge the current knowledge gap surrounding this topic.

The second implication is that this research has offered methods of potential regulation. Firstly, through its initial governance via the application of a weak version of the PP, and later establishing a specific nanotechnological regulatory framework. Again, due to the lack of academic research in relation to nanotechnology's ethical application to elite sport, there does not currently exist any regulatory systems such as this designed to effectively govern this technology. Sports that have already witnessed nanotechnology's integration are currently governing it within the confines of existing regulation, which at present may be sufficient. Due to its advanced properties, and ability to cross the boundaries of sports engineering, nanotechnology poses a genuine risk to existing regulation such as this, and it may not be effective enough to govern it fully, as shown with the previously mentioned Speedo LZR Racersuit (Dorey 2012). This research could therefore prove vital in modeling effective governance methods in relation to nanotechnology's continued safe and ethical use within elite sport.

The third and final implication, and one that considerably adds to the originality of this work, is its establishment of an ethical analytical tool for nanotechnology's use within elite sport. After reviewing this work, it became apparent that, from the methodology chapter onwards, each represented a decision-making step. When put together, each step allowed for the creation of an ethical analytical tool in order to determine how to best apply nanotechnology to elite sport (on page 172). This tool could be highly effective in terms of regulation for sporting bodies. There are a number of reasons for this, the first of which being that it is simple in nature, therefore easy to apply and understand, allowing for quick evidenced based decisions to be made in order to promote ethical progression. Secondly it is flexible, it is not fixed to any one type of nanotechnology, or any one section of sports engineering, and therefore it can be applied in order to regulate any new form of nanotechnology used within sport. Thirdly, it is universal in nature, and therefore inclusive to all sports. Consequently, an analytical tool such as this could just as easily be used in golf, as it would be in swimming for example. Finally, it is adaptable, meaning that it can also be applied in order to determine the best methods of governance in relation to other new and emerging technologies. There are therefore a number of benefits this analytical tool could bring to the effective governance of not only nanotechnology within elite sport, but other technologies also. Moreover, due to its originality, and unique nature, it will only help to further address the existing knowledge gap that exits in relation to nanotechnology's application and governance within elite sport.

4. Implications for Future Research

The research conducted in this body of work has opened a discussion in relation to nanotechnology's present and future potential ethical impacts on elite sport, alongside offering methods of regulation that could be deployed in order to govern it. In turn, it begins to address the current knowledge gap that exists in relation to present academic sporting and ethical literature. However, as with any new research on an original topic such as this, there is always scope for further improvement, providing a more substantial overview of the issues and solutions presented by nanotechnology's application to elite sport.

There are many ways that future research could be conducted in order to further develop this work. One particular example could be by conducting this work again but underpinning it with an alternative ethical framework and principle. Although, as outlined in chapter four, applied and consequentialist approaches were selected due to their logical application to this problem, it is important to outline that these are not the only ethical options that could have been utilised in order to conduct an analysis of the case studies, and review the findings. Therefore, in order to determine whether the decision outcomes generated in this research are valid, a range of alternative ethical principles could also be used to consider the case studies in order to generate comparison evidence. Thus, providing a more in depth and balanced approach to the ethical analysis of the case studies, and better informing the potential impact that this technology may have on different ethical aspects of a given sport.

Future research could also be conducted by increasing the number of nanotechnological case studies that are ethically considered for review. Although this technology is still in its infancy and its current application to elite sport is still limited, there exist a number of alternative nanotechnological case examples that could also be ethically analysed within a range of other sports beyond those discussed in this research. Moreover, alternative third party uses of this technology could also be discussed beyond the realms of horserace betting as elaborated in this research, and further expanded to consider its potential impact on the sports gaming industry for example. This again would allow for a more comprehensive ethical review of the potential impacts this technology may have on elite sport and its additional affiliations, and in turn may inform a different regulatory outcome to be suggested in order to govern nanotechnology's current and future potential use within elite sport.

Finally, future research could be conducted by undertaking a retrospective review of the case studies discussed in this work. This would take place after each nanotechnological case example has been integrated (particularly relevant for case studies two and three), allowing for their benefits and disbenefits to be formally established. The results of which could then be compared with the previous preemptive outcomes found in this research, in order to determine the accuracy of the prior ethical analysis as a predictive review model. The application of additional retrospective research such as this would also allow for the regulatory recommendations outlined in this body of work to be re-discussed and evaluated. As our understanding of this technology continues to progress, such knowledge gaps are likely to be closed, and a retrospective analysis may inform a different course of regulatory action to be applied when considering a new or current nanotechnological case example and its application to elite sport. Thus, the methods of regulation could then be reduced, or intensified depending on the outcomes of this new research.

The promotion and potential adoption of the implications discussed above would also seek to further promote the ethics and integrity of elite sport via the advancement of best practices in relation to effective technological review, governance, and regulation of nanotechnology as it continues to develop and expand within the wider domain.

Glossary of Key Terminology

Atomic Force Microscope

Is a kind of scanning probe microscope (SPM). SPMs are designed to measure local properties, such as height, friction, magnetism, with a probe. To acquire an image, the SPM raster-scans the probe over a small area of the sample, measuring the local property simultaneously (Mai n.d., para. 1).

Biomedical Engineering

A discipline that advances knowledge in engineering, biology and medicine, and improves human health through cross-disciplinary activities that integrate the engineering sciences with the biomedical sciences and clinical practice (ICL n.d., para.1).

Biomolecule

An organic molecule and especially a macromolecule (such as a protein or nucleic acid) in living organisms (MW 2019, para.1).

Biosensors

An analytical device incorporating a deliberate and intimate combination of specific biological element and physical element (Mohanty and Kougianos 2006, p.1).

Buckyball

Buckyballs are composed of carbon atoms linked to three other carbon atoms by covalent bonds. However, the carbon atoms are connected in the same pattern of hexagons and pentagons you find on a soccer ball, giving a buckyball the spherical structure (Boysen et al. 2019, para. 2).

Carbon Fibre

A material consisting of very thin filaments of carbon atoms. When bound together with plastic polymer resin by heat, pressure or in a vacuum, a composite material is formed that is both strong and lightweight (Johnson 2018, para. 1).

Carbon Nanotubes

Carbon nanotubes are large molecules of pure carbon that are long and thin and shaped like tubes, about 1-3 nanometers (1 nm = 1 billionth of a meter) in diameter, and hundreds to thousands of nanometers long (AZO Nano 2005, para.1).

Collective Bargaining Agreement

Collective bargaining agreements, in the context of professional sports, are the agreements reached between a particular league's players and the league owners. A league's collective bargaining agreement establishes specific elements of how the league will operate, such as: division of league revenues, team salary caps, free agency requirements, restrictions on player mobility, provisions regarding the drafting of players, disciplinary rules, and other general regulations of the league (Forgues 2012, para.2*).*

Deoxyribonucleic acid (DNA)

Is a molecule that contains the instructions an organism needs to develop, live and reproduce (Rettner 2017, para.1).

Embedded Technology

Embedded technologies encompass the 'behind-the-scenes' systems, such as performance analysis technologies, which provide data feedback so that teams, coaches and athletes are able to improve training programmes to support athletes achieve new levels of success in competition (Bhania et al. 2012, p.3).

Enabling Technology

Enabling technology focuses on the equipment athletes uses to compete (Bhania et al. 2012, p.3).

Enzyme

Are catalysts that allow reactions to proceed at fast rates in the mild conditions of temperature, pH, and pressure of cells (Blanco et al. 2017, p.153).

Graphene

Graphene is the name for a honeycomb sheet of carbon atoms. It is the building block for other graphitic materials (since a typical carbon atom has a diameter of about 0.33 nanometers, there are about 3 million layers of graphene in 1 mm of graphite) (Berger 2019, para.1).

Molecular Assembler

Hypothetical machines capable of manipulating matter and constructing molecules on the nano level, with scales of a billionth of a meter (Drexler 1987; Hornigold 2017, para. 3).

Motion Analysis

Is the process by which the biomechanics of a human movement is captured. The process utilizes a series of sensors and captures human movement. This movement is captured in 3 dimensions and presents information in terms of the translations of energy through the kinetic chain (Cochran n.d., para. 5).

Nanobiosensor

A Nanobiosensor may be defined as a biosensor consisting of Nanomaterials and with the dimensions on the nanometer (1 nm = 10–9 m) (Nada et al. 2011, p.92).

Nanoclays

Nanoparticles of layered mineral silicates (Merck 2019, para.1).

Nanocomposite

Composite in which at least one of the phases has at least one dimension on the nanoscale (EC 2006, p.9).

Nanomaterial

Material with one or more external dimensions, or an internal structure, which could exhibit novel characteristics compared to the same material without nanoscale features (EC 2006, p.9).

Nanomanufacturing

…the production of structures, materials and components with at least one of the lateral dimensions between 1nm and 100nm including surface and sub-surface patterns, 3D nano structures, nanowires, nanotubes and nanoparticles (Li et al. 2011, p.735).

Nanometer

Nanometer is a unit of spatial measurement that is 10^{-9} meter, or one billionth of a meter (Rouse 2019, para.1).

Nanoparticle

Particle with one or more dimensions at the nanoscale (EC 2006, p.9).

Nanoscale

Having one or more dimensions of the order of 100nm or less (EC 2006, p.9).

Nanoscience

The study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale (EC 2006, p.9).

Nanostructured

Having a structure at the nanoscale (EC 2006, p.9).

Nanotechnology

The design, characterization, production and application of structures, devices and systems by controlling shape and size at the nanoscale (EC 2006, p.9).

Nanotube

A carbon nanotube (CNT) miniature cylindrical carbon structure that has hexagonal graphite molecules attached at the edges (Rouse 2013, para1).

Performance Analysis

Performance Analysis is a specialist discipline involving systematic observations to enhance performance and improve decision-making, primarily delivered through the provision of objective statistical (Data Analysis) and visual feedback (Video Analysis) (EIS 2019, para.1).

Precautionary Principle

In order to protect the environment, the precautionary approach shall be widely applied by States according to their capability. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (CEC 2000, p. 10).

Pulse Oximeter

Pulse oximetry is a noninvasive and painless test that measures your oxygen saturation level, or the oxygen levels in your blood. It can rapidly detect even small changes in how efficiently oxygen is being carried to the extremities furthest from the heart, including the legs and the arms (Stephens 2017, para.1).

Scanning Probe Microscopes

An SPM (Scanning Probe Microscope) is an instrument used for studying surfaces at the nanoscale level (Bruker 2019, para.1).

Scanning Tunneling Microscope

T*he STM is a non-optical electron-based microscope which employs the quantum mechanical effect of tunnelling. It works by scanning a very sharp metal tip over a conducting surface within a range of several angstroms of it* (Warwick 2009, para. 2).

Technology Doping

'Technical' doping can be defined as performance-enhancing technologies that are in opposition to or threaten the integrity of sport (Constentein 2016, para.3).

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