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Sascha L. Schmidt *Editor*

21st Century Sports

How Technologies Will Change Sports in the Digital Age

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Foreword

We live in a time in which society is changing more rapidly than ever before. This can be experienced especially in the wide field of digital transformation, which is running through all areas of life and increasingly influences our behavior. Digital transformation has strongly influenced our life in general. The insights we gain from the digital world raise new questions especially when technology starts to penetrate the living organism of sport.

Prior to my time in the management of a professional football club, I worked for almost 15 years in the management of health organizations and institutions. In the early 2000s, the organizations were still using paper and pencil. Early, when compared to the sports industry, we transitioned to digital work—with digital files and integration of robotics and early methods of artificial intelligence. When I switched from healthcare to professional football in 2015, it quickly became clear that even in a prospering global mega-market, the use of technologies was burgeoning but not particularly viable. Not until that time had any club assigned innovation directly to a CEO and established it as independent subject area, with its own personnel and necessary infrastructure. Despite this lag in technology adoption, the two areas, healthcare and football, that initially seemed so different were actually very similar in terms of organization and models of thinking. And, many of the initial questions were the same.

First, there was the question of whether sport, in general, and football, in particular, would be able to provide adequate and sustainable answers to the digital challenges of the future in order to remain viable. As always, widespread buy-in to change was important. Our main sponsor SAP, with whom we worked closely, and all involved players intensively supported this challenge. Under Bernhard Peters, who had a field hockey background, many mental obstacles were removed. Even if innovative ideas were still occasionally ridiculed internally, it was more from the lack of transformational thinking than due to a fundamental obstinacy.

Under the direction of WHU-Professor Sascha L. Schmidt, the first Harvard Business Case in 2015 on the use of data analytics and our football simulator Footbonaut were developed; and our digital transformation received the attention of the wider football-loving community. It became clear, however, that to adopt technologies without clarity on the specific requirements and needs of football is not goal-oriented. We realized that we had to start thinking in terms of specific and relevant goals and went through several iterative planning loops with interdisciplinary teams to ensure this was the case.

To implement innovations in a game that has been tried and tested for over 100 years and is loved precisely because of its simplicity, demanding change must add value. Through these meaningful, iterative loops, guided by specialists, we clearly formulated our interest in innovation and value creation. We were ready to evaluate virtual reality, augmented reality, machine learning, and wearables, for example. We did not reject them as unfamiliar but did not commit to adopting any technology without understanding what the integration process was or might mean for football.

Another aspect is that sport is becoming a more advanced example of digital change. However, the performances offered must arouse the interest of the consumers and are consumed primarily because of the emotions they trigger and not to the technologies they showcase. Of course, in the course of transformation, we lost matches, we were laughed at, and we rejected technologies and ideas; but we were rigorous, disciplined, and only integrated those ideas into our daily business that really made sense. We created innovation in football without losing consumer interest or emotion.

Much of this change would not be possible without free exchange and discussion with researchers like the editor and authors of this book and an organization-wide openness toward new models of thinking. Otherwise, for example, holding the first MIT Sports Entrepreneurship Bootcamp at our stadium and using innovations like the Footbonaut or the Helix would not have become an integral part of the curriculum of a professional football club. The openness to see us as a learning system is one thing, the exchange and transfer with the best technology experts without wanting to make football scientific is another. But the job is never done.

We do people business at the end of the day; therefore, it is necessary to accept that what we have learned does not last until the end of our lives. We should break rules to make new sense and take the next steps. We should be aware that it is no longer a matter of discussing the introduction of technology but of action and experiment. If we call this process into question, we will not be able to meet the challenges for football or the industry associated with it. Sport and the sports industry must continuously demonstrate its future readiness to ensure its viability.

Through the use of technology, possibilities are created to accompany athletes or people who are enthusiastic about movement from their childhood to old age. As professionals, we are responsible for the handling of a tiny subset of elite humans whose period of sportive excellence is limited and should be optimized. Taking into account the integration of increasingly specific technology in training, rehabilitation, and regeneration as well as the emphasis on the individual even in team sports, we came to believe that more should and could be achieved by the sportsman. Through the specific use of technology, the athlete will be able to experience optimizations that we have not yet encountered before. Now, technology plays a decisive role in elite sport; soon, technology will be required not only for the athlete but also for the layman or spectator.

Experts, like the authors of this book, will guide us in the adoption of new technologies and the possible applications for sport. Of course, this opens up completely new challenges that we do not yet know how to meet. That is why this book is of immense value. The most interesting minds from different fields of research provide us, the sport practitioners and managers, with their ideas and innovations; together, we will discuss, develop, and orchestrate the future of sport. And, we should do so with the same passion as we have gained in victory and humility as we have gained in defeats. Because, at the end, it's for the love of the game.

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Preface

Today, more than ever, sport is exciting, challenging, and economically important. My first exposure to the sports industry, a good 20 years ago, came while earning my spurs in strategy consulting when we developed proposals for potential international sports clients. From a business point of view, sport was still exotic; apart from a few big players in football and a few sport mega-events, there was little to win for young professionals. While almost nobody—including me—understood the meaning of technology and data in sports at that time, I was keenly aware of my own fascination with and attraction to the sports–technology relationship. I decided then to not only invest my leisure time, but also my professional life on exploring the diverse possibilities and effects of sports, business, and technology.

Technology plays a vital role in becoming the best—on and off the pitch. In many sports, we are already at the limits of what is humanly possible. To get higher, faster, and further, athletes are like entrepreneurs who try, experiment, fail, start again, learn as they go, and eventually succeed. Off the field as well, sport business leaders must anticipate, nurture ideas early on, see developments before others, and do things more quickly than others to stay competitive. In a world of growing uncertainty, it is a difficult task; and nobody tells them how to do it. They need to anticipate and judge the relevance of technologies that will affect their business in the next five to ten years and make far-reaching decisions whether to invest in a technology or not. However, the applicability of technologies like blockchain, robotics, artificial intelligence, and augmented and virtual reality in sport, for example, often remains fuzzy.

This is where the book, *21st Century Sports: How Technologies Will Change Sports in the Digital Age*, comes into play. It is a collection of essays in which leading experts in their fields assess the impact of emerging technologies like artificial intelligence, the internet of things, and robotics on sports and vice versa. In their essays, my co-authors examine how new technologies will change sport itself, consumer behavior, existing business models, and how to prepare for it.

We also dare to look into the future of sports 20 or even 30 years ahead and think about *unknown unknowns* brought about by technology. With our book, we aim to create a compass for the next five to ten years—and food for thought for the time beyond. The book should enable athletes, entrepreneurs, and innovators working in the sports industry to spot trendsetting technologies, gain deeper insights into how they will affect their activities, and identify the most effective responses to stay ahead of the competition on and off the pitch.

I asked for fresh thinking from an international, multi-professional author team from renowned institutions such as Massachusetts Institute of Technology, Queensland University of Technology, and the University of Cambridge, and invited a few practitioners who have deep technological expertise on what lies ahead. Overall, it was particularly important for me to create a scientifically sound, but easily digestible and entertaining book with real-world examples. I hope that the readers will have as much fun reading as the authors have had while writing the book. Of course, the various expert opinions in the book do not produce a uniform picture or one conclusive future scenario, but rather reflect a variety of prospects.

Despite all the uncertainties of our new realities, it is an exciting time and the technological future of sport is likely to be even wilder than is imaginable today. But, for me, one thing is certain: the sports–technology relationship will intensify in the digital age. How we deal with this transformation in our respective fields will be a make-or-break question for sports.

Dusseldorf, Germany — Sascha L. Schmidt

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My sincere thanks go first to all my co-authors, who have put a lot of effort into applying their deep understanding of technology to the sport business and coming up with well-founded assessments of the future. Secondly, a very special thanks goes to Kat Stoneham, who worked incredibly hard to make the book project a reality. With her exceptional linguistic skills and enthusiasm for the project, she has been an important contributor and great supporter throughout the entire publishing process. We are also indebted to several outside readers who provided detailed feedback on the manuscript and particularly grateful to Erdin Beshimov, Florian Bünning, Sebastian Flegr, Kerstin Forword, Johannes Fühner, Christoph Schlembach, Ulrich Schmidt, and Dominik Schreyer.

Finally, I would like to thank my wife Larissa, my sons Lennart, Niklas, Bennet, and the rest of my family for their incredible patience and encouragement.

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Sascha L. Schmidt is Director of the Center for Sports and Management and Professor for Sports and Management at WHU—Otto Beisheim School of Management in Dusseldorf. He is also the Academic Director of SPOAC—Sports Business Academy by WHU. In addition, he is a member of the Digital Initiative at Harvard Business School (HBS), affiliated to the Laboratory for Innovation Science at Harvard (LISH) and a Research Associate at Emlyon Business School Asia. Sascha is co-author of various sports-related HBS case studies and one of the initiators and Senior Lecturer of the MIT Sports Entrepreneurship Bootcamp. Earlier in his career, he worked at McKinsey & Company in Zurich, New York, and Johannesburg, and led the build-up of the personnel agency a-connect in Germany. His research and writings have focused on growth and diversification strategies as well as future preparedness in professional sports. He is a widely published author and works as advisor for renowned professional football clubs, sports associations, and international companies on corporate strategy, diversification, innovation, and governance issues. Sascha believes in the transformative power of technology in sports and hopes that this book can contribute to a better understanding of the interrelations between sports, business, and technology. A former competitive tennis player, Sascha now runs and hits the gym with his three boys. Watching them, he is excited to see what the next generation of athletes will achieve.

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Introduction

How Technologies Impact Sports in the Digital Age

Sascha L. Schmidt

Abstract

Schmidt introduces the relationship between technology and sports in the digital age taking time to outline improvements to athletic performance, sport consumption, sports management, and governance. He also describes how technology drives the development of new sports and enhancement of traditional sport. Finally, he outlines the process by which technologies were selected for *21st Century sports: How technologies will change sports in the digital age* as well as the structure and chapters of the book.

The universality of sport reflects its evolutionary origins—human self-defense and survival mechanisms that provided a way to develop and practice hunting skills or warfare (Lombardo 2012). These formed the basis for competitive sport that has evoked deep emotional involvement in both ancient and modern times. Traditionally, athletes tested the limits of the human body, mind, and spirit. They have the desire to outwit or otherwise outperform their competitors, achieve top performances, break records, and be the best.

1 The Growing Business of Sports

Today, sport is no longer pure competition of athletes, but an entire industry in which millions of people work and earn their money. The global sports industry comprises about one percent of the global GDP and is estimated to be worth around 600–700 billion USD when sports infrastructure, sports events, sports hospitality, training,

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and manufacturing and retail of sports goods are included (KPMG 2016). Beyond money, sport helps businesses to generate emotions. Every year, billions of euros are invested worldwide to positively charge companies' brands, improve brand image, and emotionalize even functional products with the help of sport. The increasing number of new and growing sporting mega events worldwide, for example, led to global sports sponsoring volume of EUR 42 billion in 2019 (Two Circles 2019).

With all the excitement for sports, however, we cannot neglect that, from a business perspective, sport is one of the most conservative industries on the planet. In a way, sport is designed for long-term stability—to preserve competitive balance and avoid winner-take-all and natural monopoly dynamics. Every athlete must have a chance to win. The worst scenario in sports is when one athlete or team wins all the time. This is even true for commercial leagues like the NBA, the NFL, the English Premier League, and the German Bundesliga. Integrating fast-moving tech ventures into sports can create tension due to the vastly different underlying competitive dynamics of these two domains and disrupt, albeit temporarily, the competitive balance so important in sport.

Nevertheless, the sports industry is experiencing rapid growth due to new opportunities presented through new technologies and data, which is increasingly becoming the new currency in sports (Ratten 2019). With the rise of data analytics, sports act as proving ground or "laboratory" for new technologies (Michelman 2019). Because of this, a growing sports tech landscape is observable with unicorns such as FanDuel, DraftKings, Dream11, Hupu, and Peloton. According to industry experts, 2019 saw more than 2.5 billion USD in investments in global sports technology ventures especially in fitness, esports, and sports content (Penkert and Malhotra 2019).

2 The Dynamic Sports–Technology Relationship

The pace of on-field and off-field innovation has accelerated with advances in hardware, software, and data analytics. Technology and sports have a dynamic relationship. Sport is a proving ground for new technologies and technologies are, at the same time, a major source of disruption in sports. The ways that sport is played by athletes, viewed by consumers, monetized and regulated by management, are all being revolutionized by the deployment of technological innovations.[1]

2.1 Technology Improves Athlete Performance

In the past, training and competition preparation were driven by intuitive practices one followed the tried path without knowing exactly why. Nowadays, athletes,

[1]For a view of sports through the lenses of athletes, consumers, and managers, see the SportsTech framework by Penkert and Malhotra (2019).

whether professional, amateur, or leisurely, are increasingly turning to new technologies to get the most out of their physical and mental capabilities to gain competitive advantage. And the technologies fundamentally change the way they train and compete. Today, technologies used during sports activity include sensors and devices close to the body, wearables and performance tracking systems worn on the body, and smart pills and implants in the body (Düking et al. 2018). These technologies all aim to boost sportive performance by measuring and interpreting fitness, tactical, and technical data on an individual or team level to provide performance feedback and training guidance. They help athletes prevent and reduce the risk of injuries, to manage stress, and detect overloading. Most of these technologies are allowed prior to and after competition, but not during.

Technological influence is particularly observable in Paralympic competitions where a lot of innovation in sport aids, prostheses, and equipment is taking place. Many Paralympic athletes are dependent on technical aids to carry out their sport. So, innovation emerges here in the area of greatest need (von Hippel et al. 2011). The renowned futurologist Yuval Noah Harari expects new performance records to be set at the Paralympics rather than the Olympic Games. In his opinion, technical progress alone will decide when the time will come (Harari 2016). In just a few years, the technological aids for handicapped athletes will advance to the point that prostheses or exosuits will provide Paralympic athletes with additional strength, stamina, and stability that facilitate better-than-human performance (Walsh et al. 2007).

In 2012, double amputee Oscar Pistorius of South Africa was the first athlete to compete in a track event of both Olympic and Paralympic Games. Therefore, it was not a surprise that two-time Paralympic long jump champion Markus Rehm, who has beaten able-bodied athletes at the international level for years, sought to compete in the Rio Olympic Games in 2016. Rehm's Olympic dream fell short, however, as he was unable to prove that his blades did not give him an advantage over able-bodied athletes. A critical challenge remains ensuring fairness for all athletes (Kyodo News 2019).

The debate about acceptance of technical aids also has a history in able-bodied sports. In contrast to the Paralympic body, however, the Olympic body limits the use of technology to ensure fair competition. Ten years ago, for example, the International Swimming Federation started to establish boundaries for technology doping when it banned the shark-like swimsuit Speedo LZR Racer and its imitators after more than 130 world records fell in the 17 months after its introduction (Crouse 2009). Similarly, the international governing body for athletics recently announced new regulations for running shoes to counter the rising influence of game-changing equipment on athletics (The Guardian 2020).

Besides technologies that come into play on the pitch, there are numerous technologies that help improve sports off the pitch, i.e., to facilitate and improve the consumption and management of sport.

2.2 Technology Improves Sport Consumption

New technologies improve the way people consume sports and enhance the experience for fans and spectators. For example, new technical solutions make different types of content available such as original video or editorial content, sports news, and game results via traditional media distribution and sports streaming platforms. More specifically, robot-controlled drones recording in 360° provide a richer view of sporting events for streaming. Technological advances also help to connect fans with their favorite stars, teams, and leagues—both to increase fan loyalty and to enhance their sport consumption experience (Chan-Olmsted and Xiao 2019). For example, transaction platforms help ease the purchase of tickets to events or merchandise items and memorabilia. Social media technologies enable fans further to build networks and communities with others with similar sports interests.

Betting on sports and fantasy sports are recent drivers of fan engagement. It is now a sport of its own with multi-billion-dollar business. Emerging technologies provide assistance with betting real or play money on sports events and online games. Included in this category are platforms to place sports bets, support fantasy sports, game publishers, and sports prediction games to improve the player experience (Penkert and Malhotra 2019).

2.3 Technology Improves Sports Management and Governance

Besides athlete performance and sports consumption, technological innovations improve the management of sports facilities, teams, associations, leagues, events, fitness studios, and media companies. Application technologies used for professional or amateur sports teams, clubs, and venues can increase the efficiency of operations and provide better experiences for sports consumers (Harrison and Bukstein 2016). For instance, customized apps help teams or coaches to find and recruit talent, in-stadium solutions facilitate operations, and still others provide tools for organizing tournaments, leagues, races, and other major sporting events (Parent and Chappelet 2015). In addition, technical solutions can be intended for or related to the media, sponsor brands, and investors (Penkert and Malhotra 2019). For example, we see emerging platforms such as Rallyme or Sporttotal that connect brands with teams and athletes and provide marketplaces for both to raise money directly from fans and benefactors.

Officiating is another important task improvable by the application of technology. The use of microphones and earpieces, tracking systems for off-side play, goal-line technology, and video assistant refereeing emerged in professional sports in recent years. New assistance systems or laser curtains to aid referees' decision-making can help to further prevent human evaluation errors and reduce incorrect decisions on the pitch (Weisman 2014). Once they have proven their reliability, automated refereeing and scoring systems are likely to become more widespread.

2.4 Technology Enables New Classes of Athletes in Existing Competitions

Advances in new technologies present not only opportunities to enhance human athletic performance, but to augment sports by enabling new classes of athletes, like machines, to compete in existing sports (Schmidt 2018). Direct duels with machines ignite fascination. Machines can already play structured games with known rules.[2] In 1996, for example, the first man–machine duels in chess attracted a lot of public attention. When the computer Deep Blue challenged then-undisputed chess world champion, Garri Kasparov, it managed to beat the chess grandmaster in one of six games. There are plenty of subsequent examples where machines beat humans in Jeopardy, poker, or in the Chinese board game Go. Programmers also developed artificial intelligence capable of defeating people in the computer game Dota 2 without being explicitly programmed for it. With the help of machine learning, the software program taught itself the game.

There have already been interesting human–machine duels, where humans compete against each other indirectly by steering robots. RoboGames, for example, has already hosted competition of robotic athletes in football, basketball, weightlifting, table tennis, and sumo wrestling (Kopacek 2009). Moreover, the supporters of the RoboCup, a worldwide community of tens of thousands of members, pursue the vision of competing with a team of autonomous humanoid robots against the reigning football world champions—and winning by 2050.

While humans still compete against each other by steering robots in car racing, Formula E will soon no longer require human input. This is because the racing car series, built up in competition with Formula 1, will soon allow autonomous Roboracers to compete against each other. The first prototypes of these racecars are already undergoing promising tests on the track. The goal is to have different teams compete against each other with the same hardware. The competition, therefore, takes place in algorithm design. With the help of artificial intelligence that each team develops itself, the driverless racecars will compete on the asphalt at speeds of up to 300 km/h (Standaert and Jarvenpaa 2016).

2.5 Technology Drives the Development of New Sports

Propelled by user innovation, it took about 30 years for extreme sports to become mainstream and suitable for a mass market (Hienerth 2006; Hienerth et al. 2014). Today, besides improving and augmenting existing sports, emerging technologies can create new sports virtually overnight. The growth of esports[3] from a niche subculture into a 1 billion USD (and growing) global industry is the most obvious and current

[2]Although chess players do not compete based on athletic prowess, the International Olympic Committee has acknowledged the sport-like properties inherent in chess and recognized chess as a sport.

[3]Esports also known as electronic sports, e-sports, or eSports is a form of sport competition using video games.

example of technology driving sport development (Newzoo 2019). The virtual environment enables esport to implement features that we can only dream about in other sports. Although esports is currently comprised of competitive gaming among a few hundred professional gamers, the global audience for esports has already exceeded 450 million people. These esport enthusiasts are part of a community of 2.5 billion regular and casual video gamers around the globe (Newzoo 2019).

According to industry experts, in the long term, video games could become by far the largest form of entertainment in the world and esport the largest sport on the planet—even bigger than football, in terms of the number of players and spectators and in terms of sales (Scholz 2019). Adding esports to the Olympic Games seems to be rather a question of time. Apparently, from 2022 onward, esports will be an official part of the Asian Games.

Other sports, such as drone racing, have grown over the last years from a backyard hobby to a sport with international leagues, professional competitions, and a growing fan base. Similar to esports, overnight, ordinary people became superstars of the drone racing scene. Semi- and fully automated drone racing is on its way to become a serious (Jung et al. 2018) noteworthy sport discipline competing with traditional sports for the attention of the global audience. Drone racing allows the human body and mind to compete like never before and fly with unparalleled speed and agility.

Finally, there are new sports that you may not have heard of—yet—like Speedgate. This live-action sport was created with the help of artificial intelligence. Deep-learning algorithms analyzed data from more than 400 different sports, 7,300 sports rules, and 10,000 sports brand images to create it. Speedgate includes elements of rugby, soccer, and croquet. Six-player teams kick or pass a ball up and down a 180-by-60-foot field with three gates (one at the center and one at each end). The object is to score points by kicking the ball through one of the end gates (Ha 2020).

3 Emerging Technologies Will Shape the Future of Sports

The purpose of this book is not only to evaluate emerging technologies regarding their impact on sports in the next five to ten years, but also to take a broad look into the future of sports 20 or even 30 years ahead and to think about *unknown unknowns*. Doing so, we gain familiarity with and examine how new technologies will change sport itself, consumer behavior, and existing business models. Instead of applying a systematic technology forecasting (Cetron 1970), scanning (Van Wyk 1997), or road mapping approach (Phaal et al. 2004; Walsh 2003), we take an exploratory approach that allows us to more creatively gain insight on our subject (Reiter 2017). Although we can give some indication as to the why, how, and when emerging technologies will impact sports, the exploratory findings of the book are not immediately useful for decision-making by themselves. They serve rather to identify technologies, trends, and developments early on and to raise attention to the opportunities and threats associated with them.

3.1 Quantitative Versus Qualitative Technology Forecasting

The desire to predict the future is a part of human nature and we find many examples throughout history. In ancient Greece, for example, the Oracle of Delphi foretold the future and became one of the most famous cult sites in history (Häder 2009). Now, forecasting is the process of making predictions about the future based on historical and present data—most commonly by using trend, indicator, and impact prognosis (Armstrong 2001). Nevertheless, predicting the development of a technology and its future impact is a complex task. Quantitative forecasting models are usually applied to short- or intermediate-range future scenarios and used to forecast future data as a function of past data. They are appropriate when enough historical data is available and when some of the patterns in the data are expected to continue (Rescher 1998). The crux is, however, that in disruptive times, interpolation of historical data no longer allows predicting the future. Since our world might change even more radically in the coming decades than in the previous hundred years, quantitative technology forecasts will not become any easier. In just a few decades, a new world will have emerged—our great-grandchildren will not even be able to imagine the world we now know.

However, how athletes, consumers, and managers deal with new technologies remains uncertain and ambiguous. To assess emerging technologies and their future impact on sports, we build on the personal judgment and intuition of true subject matter experts with decades of professional experience. This kind of qualitative technology forecasting is usually applied to intermediate- and long-range scenarios and appropriate when past data are not available or disruptive development is foreseeable (Archer 1980).

3.2 Selection of Emerging Technologies Relevant to Sports

To select the most relevant technologies for the future of sports in the digital age, we first looked at technology forecasting reports and studies. There are a number of established market research and intelligence firms, tech blogs, and platforms (for example, Gartner, CB Insights, ZDNet, and TechCrunch, among others) in technology forecasting, scanning, and road mapping. They have all developed tools and methods to analyze millions of data points on venture capital, startups, patents, partnerships, and news mentions to predict which emerging technologies will experience breakthroughs and develop their full potential; they also predict technology timelines. For instance, every year US market researcher Gartner examines new emerging technologies and arranges them on what they call the *Emerging Technologies Hype Cycle*. We took their Hype Cycle for 2017, 2018, and 2019 as a basis to select the most relevant emerging technologies for the sports industry (Gartner 2017, 2018, 2019). We focused on technologies that seem likely to be disruptive, whose full potential will be reached in five to ten years, and for which there are early use cases in sports. From the 35 technologies of the Hype Cycle, we have selected only those technologies that will be particularly relevant to the sport of the future. Scholars and practitioners were then invited to write a chapter outlining their predictions for the selected technologies in sport. Of course, the chosen technological innovations are base technologies and not discrete items; they are somehow intertwined as artificial intelligence and robotics, for example, cannot be isolated.

3.3 Book Structure

We have organized this book into five sections: An introductory section, three sections of technologies, and an outlook section.

I. Introduction. Beyond this chapter, in which we introduce our thinking and the structure of the book, we dedicate this section to capture the emergence of the sportstech industry and its current state. Nicolas Frevel, Sascha L. Schmidt, Daniel Beiderbeck, Benjamin Penkert, and Brian Subirana propose a "Taxonomy of sportstech" to provide an all-encompassing structure of technology use from the athlete, consumer, and management point of view. Next, Sanjay Sarma, Brian Subirana, and Nicolas Frevel discuss in "How Thesis Driven Innovation Radars could benefit the sports industry" how sports organizations and their management can benefit from a systematic approach to handling emerging technologies in sport. In doing so, they make the case for the application of *Thesis Driven Innovation Radars*.

II. Physical technologies. The first technology category is mostly about hardware. It includes advanced materials, robotics, sensors, devices, fibers, textiles, coatings, composites, nutraceuticals, biomedical engineering, etc. All these technologies play a key role in capturing data. Five chapters make up this section; we introduce them each in turn:

Josh Siegel and Daniel Morris explore in "Robotics, automation, and the future of sports" the growing influence of robotics and automation on sports and potential resultant future states including new models for spectator experience. They consider how robotics and automation create opportunities for improved athlete training and detail how robotics and automation have augmented sports to date by allowing new athletes to compete creating new sports and providing a playing field for intellectual athletes.

Frank Kirchner explores in "Robotics and AI: How technology may change the way we shape our bodies and what this does to the mind" the possibilities of some of the most recent developments in robotics and artificial intelligence to shape the future of physical activity and the effect this may have on both the body and the mind. He provides existing examples as well as future possibilities for robots as athletes, robots as trainers and teachers, and robots as human athletic opponents and as therapists. Kirchner concludes with possible effects on the human body and mind if mankind enters extensive physical interaction with intelligent machines.

Martin U. Schlegel and Craig Hill explore in "The reach of sports technologies" the use of sports technologies in order to provide the basis for validation, transfer, and diffusion of knowledge into fitness, wellness and health, as well as occupational health, safety, and defense. They explain how sports technologies impact multiple verticals including insurances, stadium set up and maintenance, and broadcasting. Finally, they explore the challenges presented by the use of sports technologies including the barriers to open standards, security, and privacy.

Daniel Beiderbeck, Harry Krüger, and Tim Minshall highlight in "The future of additive manufacturing in sports" the present and projected impact of additive manufacturing technologies on the sports ecosystem. They describe the advantages of additive manufacturing and outline the benefits for the sports industry. They also illustrate how the interplay between additive manufacturing and technological advancement in other fields like artificial intelligence, sensor technology, and robotics can create new products and business models.

Finally, Dietmar W. Hutmacher offers in "The current state and future of regenerative sports medicine" an overview of the progression of currently available regenerative treatment concepts and a summary of the different modalities of available and potential treatments. Finally, he offers a critical, though visionary, view on how regenerative sports medicine technologies may lead to new treatment concepts and increasing engagement of both sports' injury patients and physicians.

III. Information processing technologies. This technology category is mostly concerned with data handling and information processing. It includes technologies in the realm of big data, advanced analytics, artificial intelligence, blockchain, machine learning, quantum computing, etc. Five chapters make up this section; we introduce them each in turn:

First, Benno Torgler examines in "Big data, artificial intelligence, and quantum computing in sports" the exciting possibilities promised for sports by technologies like big data, artificial intelligence, and quantum computing. He concludes that together and separately, the technologies' capacity for more precise data collection and analysis can enhance sports-related decision-making and increase organization performance in many areas.

Christina Chase argues in "The data revolution: Cloud computing, artificial intelligence, and machine learning in the future of sports" that data is the currency by which competitive advantage is won and lost. Those who find creative ways to unlock and harness it—largely through the employment of artificial intelligence, machine learning, and cloud computing, which she discusses in turn—will be the champions of tomorrow.

Sandy Khaund gives in "Blockchain: From fintech to the future of sport" an explanation of the oft spoken about, but little understood, blockchain technology. He then walks the reader through likely applications of the blockchain technology on and off the sporting field taking time to outline the revolutionary power of smart contracts for athlete compensation, gambling, and even broadcasting contracts.

Martin Carlsson-Wall and Brianna Newland survey in "Blockchain, sport, and navigating the sportstech dilemma" the current blockchain tech landscape in sport and introduce the sportstech dilemma. To guide companies navigating this dilemma, they propose three strategic questions—concerning the level of integration into the sports ecosystem, potential for a hybrid business model, and geographic footprint. Finally, they look further into the future and see unexpected possibilities for blockchain in sport.

Michael Bartl and Johann Füller introduce and explore in "The rise of emotion artificial intelligence: Decoding flow experiences in sports" emotion-based artificial intelligence, which they argue has the potential not only to radically change the way sports are trained, but also how sport is experienced and consumed. Their chapter illustrates how affective states can be measured with the help of artificial intelligence and how the provided analytics may impact the sports experience.

IV. Human interaction technologies. This technology category is mainly about human interaction. It plays a particularly important role in, e.g., fan engagement with technologies such as virtual reality, augmented reality, mixed reality, extended reality, voice, and mobile technologies in general. Three chapters make up this section; we introduce them each in turn:

Ben Shields are Irving Rein argue in "Strategies to reimagine the stadium experience" that the in-stadium sports experience is important and worth fighting for, despite the challenges presented by seemingly limitless sports and entertainment options, increasing ticket cost, and transportation issues. To persuade fans to spend their time and money attending sporting events, they contend that sports organizations will need to rethink their conception of the stadium and offer four strategies to do so including leveraging new technology like augmented reality and virtual reality.

Andy Miah, Alex Fenton, and Simon Chadwick consider in "Virtual reality and sports: The rise of mixed, augmented, immersive, and esports experiences" how virtual reality, augmented reality, mixed reality, and extended reality are being integrated into the sports industry. They focus on how new, digitally immersive sports experiences transform the athletic experience for participants and audiences and create new kinds of experience that, in turn, transform the sporting world.

Finally, Johanna Pirker demonstrates in "Video games, technology, and sport: The future is interactive, immersive, and adaptive" how video game events and streaming experiences offer interesting new ways of interaction between the viewer and the player or the viewer and the game. She reasons that traditional sports can follow successful strategies like these. In addition, she shows how virtual reality, head-mounted-displays, and augmented reality devices are opening new avenues for the future of spectator experience in sports.

V. Outlook. In this final section, we offer a potential view of the technology-driven future aided by "Impossible sports" by Brian Subirana and Jordi Laguarta. To illustrate how technologies will shape future sports, they explore an imaginary future following a fictional character and her family through a day in their lives. They highlight potential applications of technologies in the fields of the internet of things, robotics and automation, information processing, communications, and legal programming in new sports.

Finally, in "Beyond 2030: What sports will look like for the athletes, consumers and managers" we pick up the reins once again to investigate a more distant future and, with the help of our authors, discuss how technology will influence sports up to 30 years from now. We explore this far-out future from three perspectives: the athlete, the consumer, and the manager. In the end, we even dare to think beyond this 30-year mark in sports and the upcoming opportunities and threats presented by technology.

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Taxonomy of Sportstech

Nicolas Frevel, Sascha L. Schmidt, Daniel Beiderbeck,
Benjamin Penkert, and Brian Subirana

Abstract

In this chapter, the authors provide a snapshot of the opportunities, challenges, and development of the sportstech industry and propose a sportstech taxonomy comprised of the definition of sportstech and the SportsTech Matrix. Their goal is to provide a common understanding and a useful tool for researchers and practitioners alike. In so doing, they define sportstech based on established understanding of sports and technology, introduce the SportsTech Matrix, and exemplify how to apply it with use cases for a variety of stakeholders. The SportsTech Matrix provides an all-encompassing structure for the field of sportstech along two angles: The user and tech. Together, the two angles capture how different types of technologies provide solutions to different user groups.

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1 Introduction

The sports industry at large has seen exceptional growth over the past decades, and it continues this development at a remarkable pace. According to the European Parliament, sports' impact on the economy and society amounts to almost 3% of EU gross value added and over seven million people have sports-related jobs—3.5% of total EU employment (Katsarova & Halleux, 2019). As it grew, the sports industry matured and professionalized in an unprecedented way. Throughout development, innovation in sports technique and equipment has always played a decisive role: In sports, a fraction of a second can make the difference between winning and losing; and innovation and technology can often be the distinguishing factor. Examples of the innovations that have sustainably altered their sport in a disruptive way are manifold—some can even be described as Schumpeterian.[1] For example, the invention of the Fosbury flop allowed a mediocre athlete, Richard Fosbury, to clinch an Olympic gold medal (van Hilvoorde, Vos, & de Wert, 2007); the introduction of the forward pass made American Football a much safer sport (Oriard, 2011); and Jan Boklöv's transformation of ski jumping from skis held in a V-shape instead of in parallel allowed for both longer and safer jumps (Virmavirta & Kivekäs, 2019).

Today, many athletes have perfected their technique to an extent that leaves little room for improvement from an athletic point of view. If we look at the 100 meters, it is hard to imagine that anyone will ever sprint much faster than Usain Bolt's astonishing 9.58s, given the natural limitations of the human body (Nevill & Whyte, 2005). In most professional sports, the rate of performance improvement has stagnated and we see a plateauing of performance and records (Berthelot et al., 2008, 2010; Nevill, Whyte, Holder, & Peyrebrune, 2007). Linear performance improvements in the twentieth century, as discussed by Whipp and Ward (1992),[2] are a thing of the past; "sport performance may cease to improve during the 21st century" (Berthelot et al., 2010). Lippi, Banfi, Favaloro, Rittweger, and Maffulli (2008, p. 14) found that "future limits to athletic performance will be determined less and less by innate physiology of the athlete and more and more by scientific and technological advances and by the still evolving judgment on where to draw the line between what is 'natural' and what is artificially enhanced." In their paper, Balmer, Pleasence, and Nevill (2012) discussed the various mechanisms[3] that have historically led to better performance and argued that technology will be necessary for any significant gain in the future.

[1] A "Schumpeterian innovation is primarily radical and disruptive in nature" (Galunic & Rodan, 1998, p. 1194). According to Schumpeter, "developments [= innovations] are new combinations of new or existing knowledge, resources, equipment and the alike" (Schumpeter, 1934, p. 65).
[2] Whipp and Ward (1992) demonstrate that the world record progression in standard Olympic events ranging from 200 meters to marathon is linear throughout the twentieth century.
[3] These mechanisms include "increased participation, professionalization (of participants and coaches), natural selection, improved training, nutrition and psychological preparation, advances in technique, and technological innovation in the design of equipment and ergonomic aids" (Balmer et al., 2012, p. 1075).

In their perpetual pursuit of records and better performance—Citius, Altius, Fortius[4] as the Olympic motto proclaims—athletes will increasingly depend on advances in sportstech (Dyer, 2015). While technology-driven progress in performance could already be observed in the past, it will be of paramount importance in the future. Performance in many sports has seen improvements through technology, for example, cycling, the 100 meters, the javelin, and the pole vault (Balmer et al., 2012; Haake, 2009), long jump, high jump, triple jump (Balmer et al., 2012), amputee sprinting (Dyer, 2015), and swimming (Foster, James, & Haake, 2012; Stefani, 2012), to name but a few. As these examples suggest, application of technology was limited to only a few aspects of sport such as improving athletes' immediate performance. However, we have seen a significant change in recent years. Technology now affects nearly all aspects of sports: How athletes compete and train, how fans consume and engage, and how managers run their organizations. Advanced materials, data-driven solutions, and information and communication technologies such as augmented reality are the new sources of competitive advantage. Sportstech has evolved from a niche topic to a key component in sports. As a consequence, the sports ecosystem is ever more complex and increasingly reliant on advanced technologies (Fuss, Subic, & Mehta, 2008).

Sportstech embraces a lot more than elite athletes' pursuit of sportive perfection. It is an emerging industry that is taking shape. No longer limited to the aspects discussed above, sportstech today is a creative force that has spawned a host of new: New sports like drone racing and esports, new ways of fan engagement like betting and fantasy sports, new ways of sports consumption through augmented reality, and New ways to manage sports organizations through big data analytics. Sportstech is not restricted to the elite athlete; the wider or mass audience is the target of tracking devices and fitness applications, for example.

Meanwhile, the sportstech venture scene has gained significant momentum. Investors have realized the potential of sportstech as a promising market for venture investing; cumulatively, more than 12 billion USD were invested in sportstech between 2014 and 2019 (Penkert & Malhotra, 2019). Simultaneously, the number of startups operating in this area has increased rapidly and established corporates such as Intel or Comcast have also heavily invested in sportstech solutions (cf. Ogus, 2020). An entire sportstech ecosystem has developed with numerous accelerators, hubs, and venture funds. In 2018, the sportstech market was valued at 8.9 billion USD and is estimated to reach 31.1 billion USD by 2024 (MarketsandMarkets, 2019).

Developments in the sportstech industry have caught the attention of scholars as well. The increase in analyses of individual areas of sportstech highlights the relevance of this field of research and the potential as its own stream of research[5] (cf. Ratten, 2018). However, there is a lack of overarching taxonomies, frameworks,

[4]Latin for faster, higher, stronger.

[5]The number of publications on Google Scholar for the keyword "sportstech" has increased from 25 in 2010 to 114 in 2019, an increase of more than 450% (see Scholar PLOTr; https://www.csullender.com/scholar/).

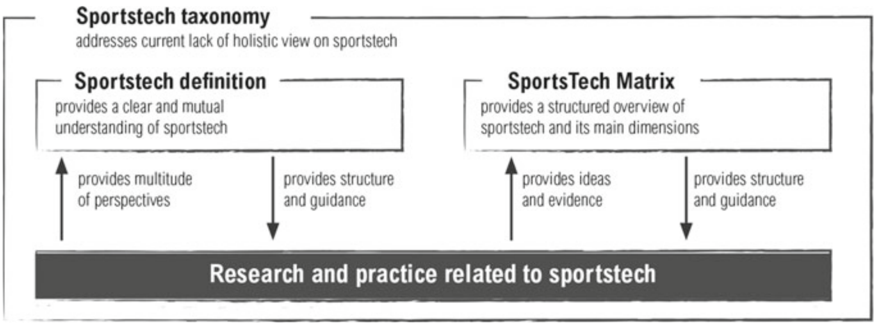

Fig. 1 Sportstech taxonomy

models, and guidelines for sportstech (cf. Ratten, 2017). Such structuring elements are needed to foster research that can inform the relevant stakeholders—from researchers to athletes, fans, and management as well as owners and investors. To fill this gap, we propose a sportstech taxonomy[6] (see Fig. 1), which includes the definition of sportstech and a SportsTech Matrix; the overarching goal is to establish a shared understanding of the term sportstech and to guide the investigation of the intersection between sports and technology.

In the next section, we develop a definition that captures the meaning, use, function, and essence of the term "sportstech," building on commonly used definitions for sports and technology. We will then review the characteristics and developments of the sportstech industry, before introducing the SportsTech Matrix and providing examples of how it can be used by both researchers and practitioners. Finally, we will conclude this chapter.

[6]A taxonomy is an approach to classification that groups subjects into a posteriori categories that inductively result from analysis (Rich, 1992). That is, a taxonomy's categories are based on the characteristics of their respective subjects, "so the categories are both exhaustive and mutually exclusive" (Fiedler, Grover, & Teng, 1996, p. 12). In contrast, in a typology, categories are defined a priori and subjects are deductively assigned to these categories. Thus, "typologies and taxonomies represent two fundamentally different approaches to classification" (Fiedler et al., 1996). Taxonomies are particularly useful for unexplored fields of study as both the number and nature of categories are not preordained. Developing a taxonomy typically includes multiple steps from defining classification criteria and categorizing items to evaluating the resulting categories. For new phenomena, a taxonomy may start from experience and expertise, while at some point it needs to result in emergent theory (Fiedler et al., 1996). In addition, it is very important that the taxonomy "mirror[s] the real world" (Rich, 1992, p. 777), that is, its categories and subjects must be identifiable by researchers and practitioners and it must be compatible with their views. As a result, our suggested taxonomy is predominantly based on experience and expertise, however, we largely built on the preexisting and tested SportsTech Framework and evaluated the resulting categories against the current largest sportstech database, SportsTechDB (Penkert & Malhotra, 2019).

2 Defining Sports, Technology, and Sportstech

Before diving into the characteristics of the sportstech industry, we provide clear definitions of sports and technology, respectively, and a definition of sportstech.

2.1 The Definition of Sports

Defining sports in a way that everyone would agree on is far from easy and anything but trivial.[7] If you agree with Nike co-founder Bill Bowerman, then "if you have a body, you are an athlete" (cf. Nike, 2020). However, to separate sports from other leisure or professional activities varies by source and largely depends on the perspective. That is, answering what qualifies and what does not qualify as a sport may differ significantly among medical, societal, ethical, and other considerations.[8] Two definitions that have been seminal in this field stem from sport sociology (Guttmann, 1978) and sport philosophy (Suits, 2007). Jenny, Manning, Keiper, and Olrich (2017), for example, have received much attention for their work on esports and the definition of sports. Building on the definitions of Guttmann and Suits, they provide an overview of the characteristics of sport, according to which a sport must (i) "include play (voluntary, intrinsically motivated activity)," (ii) "be organized (governed by rules)," (iii) "include competition (outcome of a winner and loser)," (iv) "be comprised of skill (not chance)," (v) "include physical skills (skillful and strategic use of one's body)," (vi) "have a broad following (beyond a local fad)," and (vii) "have achieved institutional stability where social institutions have rules which regulate it, stabilizing it as an important social practice" (p. 5).

Outside of academia, a clear definition of sports is relevant in many regards. Beyond the interest of billions of people as a popular pastime, sport has strongly grown in societal and economic significance. As a result, increased importance has been given to sports policy and the matter has been pushed higher up the European Union (EU) agenda (Katsarova & Halleux, 2019). The EU follows a definition of sport developed by the Sports Charter of the Council of Europe where "sport means all forms of physical activity which, through casual or organized participation, aim at expressing or improving physical fitness and mental well-being, forming social relationships or obtaining results in competition at all levels" (Council of Europe, 2001). Another interesting perspective to this discussion comes from the Global Association of International Sports Federations which aims at providing a "pragmatic description of activities which could be considered as a sport" (Sportaccord,

[7]The definition of sports can, however, have severe consequences for certain stakeholders, for example, when it comes to federation's qualification as a sport federation (e.g., consider drone racing) or access to funding available to sports (e.g., consider esports). Given the technological, societal, etc., advancements today, the need for a refinement of the definition of sports might become necessary.

[8]For example, esports might not be considered a sport given its potential lack of physicality; and some forms of martial arts might not be considered a sport given their potentially harmful nature (cf. Sportaccord, 2011).

2011). Following their definition, sport "should have an element of competition, [. . .] in no way be harmful to any living creatures, [. . .] not rely on equipment that is provided by a single supplier, [. . . and] not rely on any 'luck' element specifically designed into the sport" (Sportaccord, 2011). While some elements of this definition overlap with Jenny et al. (2017), other elements such as the explicit mentioning of no harm to living creatures differ.

For the purpose of deriving a sportstech taxonomy, we follow the definition of Jenny et al. (2017) as it is based on widely accepted definitions from scholars like Guttman (1978) and Suits (2007) and, in our view, captures the most comprehensive and succinct meaning of sports.

2.2 The Definition of Technology

The term technology is widely used, however, there are different levels of understanding among scholars, practitioners, and even philosophers. Earlier definitions of technology focused much more on physical tools, machines, and devices as well as the required skills to use them (Bain, 1937). Over time, less tangible facets such as knowledge, methods, and procedures were included; and definitions focused on the application of that knowledge in the provision of goods and services (Khalil, 2000). Similarly, Van De Ven and Rogers (1988) defined technology as "knowledge that is contained within a tool for accomplishing some function; the tool may be a mental model or a machine" (p. 634). For the purpose of developing a taxonomy of sportstech, we build on the commonly used definition from Rogers' Diffusion of Innovation Theory (Rogers, 2003):

> A technology is a design for instrumental action that reduces the uncertainty in the cause-effect relationships involved in achieving a desired outcome. A technology usually has two components: (1) A hardware aspect, consisting of the tool that embodies the technology as a material or physical aspect, and (2) a software aspect, consisting of the information base for the tool.

This definition embodies all relevant facets of technology. It is not too narrow as to exclude certain types of technology and at the same time, it clearly states the purpose of technology in achieving a desired outcome and its instrumental role in that process. It also addresses hardware and software, which can be technology independent, but are usually both part of a given technology.

2.3 The Definition of Sportstech

Sports and technology have been intertwined for hundreds of years, but the term sportstech reached its current prominence only in the past few years. Previously, technology in sports had a mostly constitutive function; for many sports (e.g., skiing, cycling, ice skating[9]), technology is a necessary condition to exist at all (Loland, 2009). As health and safety concerns gained increasing attention, technology played a significant role in protecting athletes against harm and injuries (Waddington & Smith, 2000). These technologies range from the obvious, helmets and protective gear, to the more imperceptible, like shock-absorbing soles. Over time, technology was increasingly used to improve athletic performance, both during competition and in training. Examples include training machines such as treadmills, wind tunnels to improve aerodynamics, biochemical means of performance-enhancement, or drag-reducing, high-tech swimwear fabrics that resulted in the setting of over 130 swimming world records in 2008 and 2009 (Crouse, 2009; Tang, 2008).[10]

A broad definition—that we agree with—comes from Loland (2009, p. 153); he defines sport technology as "human-made means to reach human interests and goals in or related to sport." Similarly, we understand sportstech as the intersection of sports and technology. When technology provides a solution in the larger sphere of sports, we consider it sportstech. Therefore, beyond the athlete-focused aspects discussed above, sportstech also includes areas such as broadcasting, ticketing, sponsoring, digital media, smart venues, and fan engagement. It has also significantly aided adherence to the rules and officiating of sports through, for example, the shot clock in basketball, the hawk-eye in tennis, the video-assisted referee and goal-line technology in football, and the photo finish in many sports (cf. Kolbinger & Lames, 2017).

As the sector could benefit from a consistent use of terminology, we would also like to provide our view on the spelling of sportstech. Multiple versions still exist including sportstech, sports tech, sporttech, sport tech, sportstechnology, sports technology, sporttechnology, and sport technology. We advocate for the universal use of "sportstech." We chose "sports" over "sport" as it better reflects the notion of all sorts of sports instead of an individual sport. And, we chose the spelling "sportstech" rather than "sports tech" following other tech industries such as fintech, medtech, biotech, edtech, agritech, foodtech, cleantech, greentech, etc.

Finally, we wish to emphasize that sportstech is by no means a new phenomenon, it has been around for centuries. However, the term gained significant attention and popularity over the past couple of years and has diversified to accommodate the different needs and wants of a broadened stakeholder base (Fuss et al., 2008).[11]

[9]For example, ice skating may have been a sport for as long as people have inhabited Finland. There is evidence of bone skates 5,000 years ago and of bone implants as far back as 10,000 years ago (Choyke and Bartosiewicz, 2006; Hines, 2006).

[10]Technology as it is applied in sports often operates on a fine line between what is considered fair competition and doping. For example, high-tech swimwear fabrics have been banned from the sport while goggles are still allowed, even though when used for the first time during the 1976 Olympics they resulted in a similar waterfall of broken world records (Tang, 2008).

[11]When Adi Dassler upgraded football boots with studs, that was an early form of sportstech. Of course, the nature of most sportstech solutions has changed over time; when we talk about sportstech today, we are more likely to think of a machine learning algorithm that helps Formula 1 teams predict race strategy outcomes than of football boots.

3 The Sportstech Industry

The sportstech industry has experienced and is expected to experience exceptional growth with a compound annual growth rate of more than 20% between 2018 and 2024; this means growth from 8.9 billion USD in 2018 to 31.1 billion USD in 2024 (MarketsandMarkets, 2019). Some forecasts are even more optimistic, valuating the sportstech industry at 27.5 billion USD in 2018 with estimates as high as 93.8 billion USD by 2027 (Bertram & Mabbott, 2019). The industry's growth is also reflected in venture investing whereby more than 12 billion USD were invested between 2014 and 2019 (Penkert & Malhotra, 2019). While the world's largest companies were not very active in sportstech as recently as a decade ago, they are now entering the space at an increasing pace. For example, the Global Sports Innovation Center powered by Microsoft (GSIC) connects the sports industry to innovation through networking, research, showcasing, and supporting startups (Global Sports Innovation Center, 2020). SAP built its own sports and entertainment unit that supports clients to "transform traditional methods in athlete management, scouting, health, fitness, training, development, game execution, and compliance through digital transformation" (SAP, 2020). There is an ongoing paradigm shift as corporates start to realize that sportstech holds great potential for them (cf. Ogus, 2020).[12]

One of the key contributors to this paradigm shift is digitalization. Many industries and markets have been disrupted by technologies and digital transformation (Verhoef et al., 2019). These changes occur on various levels from changing consumer demands (cf. Lemon & Verhoef, 2016) to digital attackers that disrupt less digitally advanced companies (Goran, LaBerge, & Srinivasan, 2017). Some examples, such as Spotify (cf. Wlömert & Papies, 2016) or Netflix (cf. Ansari, Garud, & Kumaraswamy, 2016), are well known. Like any other industry, the sports industry is not immune to these developments, despite its rather traditional characteristics. Sportstech could particularly benefit from these developments; many sportstech companies build their ventures on digitalization and are thereby more likely to be the driver of change in sports rather than the object of change.

Despite the variety of opportunities for sportstech, there are still many challenges that need to be overcome as they are potential barriers to growth. The sportstech industry is still very fragmented in many regards—geography, talent and skills, access to funding, and so on (cf. Proman, 2019b). In addition, the adoption of technology in the sports industry remains an issue and is often rather ad hoc than strategic[13]; thus, technology does not contribute to competitive advantage as much as it could. One of the main reasons for low technology adoption rates is the lack of

[12]This paradigm shift is intensified as the increasing combinations and intersections of business models create new and highly complex environments. Just as automotive industry incumbents fear Google or Apple as market entrants, many broadcasting incumbents in the sports industry fear Amazon or Facebook as potential entrants.

[13]For example, many professional football clubs still consider technology as "nice to have" rather than a strategic imperative (Raveh & McCumber, 2019). According to a survey conducted by PwC among more than 500 sports leaders across 49 countries about the role of innovation in sports

(access to) talent and skills (Bertram & Mabbott, 2019). According to a survey among more than 100 sportstech experts,[14] the main factors holding back the adoption of sportstech are "unqualified decision makers, risk aversion, and cost" (Proman, 2019a). With respect to sportstech venturing, many startups and ventures experience difficulties with funding, as access to funding is very limited particularly for early-stage startups (Bertram & Mabbott, 2019). In addition, startups often lack access to other resources (e.g., talent) and relationships or networking opportunities with the right people in the industry (Ogus, 2020). Finally, sportstech protagonists could benefit from an intensified collaboration with universities and other research institutes. So far, it is to navigate industry-leading research in sportstech (Bertram & Mabbott, 2019).

The developments in sportstech also present associations, leagues, and clubs with major challenges. They are responding in multiple ways. Many of them have already set up centers of expertise to make rapid progress in sportstech and to make the best possible use of the opportunities that arise. Examples of such centers include UEFA Innovation Hub, DFB Academy with its recently established Tech Lab, Barca Innovation Hub, or Real Madrid Next. An alternative way to engage with sportstech is through startup competitions such as LaLiga Startup Competition, Werder Lab, City Startup Challenge, and EuroLeague Basketball's Fan Experience Challenge and through accelerator programs such as the 1. FC Köln HYPE Spin Accelerator. There are also approaches that focus more on strategic partnerships and investments in sportstech startups such as DFL for Equity.

Regarding investors, several interesting trends can be identified. First, there is an increasing emergence of sportstech-specific investors such as Sapphire Sport (with City Football Group as anchor investor), Courtside Ventures, Elysian Park Ventures, Causeway Media Partners, and SeventySix Capital. They are mostly equipped with smaller funds[15] and tend to participate in earlier rounds of funding. Despite increasing activity from sportstech-specific investors and their notable investments including unicorn candidates Strava, Tonal, and Zwift, the sportstech industry could benefit from more dedicated funds to generate even more growth from within the industry (Penkert & Malhotra, 2019). Second, more and more industry-agnostic investors have gained interest in sportstech, including some of the world's leading investors such as Accel, Andreessen Horowitz, Sequoia, Softbank, and Tencent. So far, their activity has proven to be successful with unicorn startups such as Peloton, DraftKings, FanDuel, Hupu, and Dream11 (Penkert & Malhotra, 2019). A continued influx of such high-profile investment companies is needed to develop the industry further and increase the overall funding. Third, athletes are taking stakes in the space with their own funds or investment companies (cf. Bloomberg, 2019). Examples include Serena Williams' Serena Ventures, Kevin

organizations, the majority of sports organizations do not have concrete innovation strategies in place (PwC, 2019).

[14] Experts included founders, investors, and industry professionals in sportstech (Proman, 2019a).

[15] For example, Sapphire Sport launched a 115 million USD venture fund to invest in sports and technology in early 2019 (Ogus, 2019) and Courtside Ventures initiated a 35 million USD fund in 2016 (Heitner, 2016).

Durant's 35 Ventures, and Aaron Rodgers' RX3 Ventures (Abraham, 2019). Athletes pursue different strategies to grow their wealth to prepare for life after sports. Next to their financial investment, athletes typically bring additional benefits to the cap table such as their network and their social media following (Rooney, 2020).

Although sportstech has gained significant relevance in business practice, there is surprisingly little research on sportstech in the academic literature (Ratten, 2017). Most of the existent scientific work is fragmented and has a very specific focus like sports innovation (Ratten, 2016; Ringuet-Riot, Hahn, & James, 2013; cf. Tjønndal, 2017) or comes from adjacent disciplines such as brand management (cf. Pradhan, Malhotra, & Moharana, 2020), biomechanics (cf. de Magalhaes, Vannozzi, Gatta, & Fantozzi, 2015), and ethics (cf. Evans, McNamee, & Guy, 2017). A systematic review that examines sportstech in its entirety is certainly missing. Existing literature reviews focus on individual aspects such as ethics of sportstech (e.g., Dyer, 2015), statistical analysis in sports (e.g., Sidhu, 2011), integrated technology[16] and microtechnology sensors in team sports (e.g., Cummins, Orr, O'Connor, & West, 2013; Dellaserra, Gao, & Ransdell, 2014), machine and deep learning for sport-specific movement recognition (e.g., Cust, Sweeting, Ball, & Robertson, 2019), human motion capture and tracking systems for sport applications (e.g., Barris & Button, 2008; van der Kruk & Reijne, 2018), augmented reality and feedback strategies in motion learning (e.g., Sigrist, Rauter, Riener, & Wolf, 2013), ubiquitous computing in sports (e.g., Baca, Dabnichki, Heller, & Kornfeind, 2009), artificial intelligence in the analysis of sports performance (e.g., Lapham & Bartlett, 1995), or practice-enhancing and human-enhancement technologies (e.g., Farrow, 2013; Miah, 2006).[17] In addition, many reviews focus more on practically relevant themes such as illustrating the latest technological developments. Exemplary works of this type look at virtual environments for training in ball sports (e.g., Miles, Pop, Watt, Lawrence, & John, 2012) and data collection and processing technologies (e.g., Giblin, Tor, & Parrington, 2016).

For now, sportstech is an emerging industry that is still taking shape. However, given the current developments and dynamics, it is clearly one of the most intriguing industries to be active in right now.

4 The SportsTech Matrix

We develop the SportsTech Matrix as part of our taxonomy to provide an all-encompassing structure and a common understanding for the field of sportstech. It is intended to help both researchers and practitioners alike, even though their respective use of the matrix might differ. At its core, the SportsTech Matrix consists

[16]Integrated technology refers to accelerometers, global positioning systems (GPSs), and heart rate monitors.

[17]These are a few exemplary reviews from different fields of research; the enumeration is not exhaustive.

of two angles: A user angle and a tech angle. For the user angle, we rely on a framework from Penkert (2017, 2019) and Malhotra (2019). It involves three different user groups that are relevant in sports: athletes, consumers, and management. For the tech angle, we developed a categorization of technologies suitable for capturing sportstech. Together, these two angles capture how different types of technologies provide solutions to different user groups in the realm of sports. Please refer to Fig. 2 for an overview of the SportsTech Matrix.

4.1 User Angle

The user angle of our SportsTech Matrix builds on the SportsTech Framework (see Fig. 3) by Malhotra (2019) and Penkert (2017, 2019), which is based on the review of thousands of sportstech startups.[18] The framework is structured along the main user groups in sports and has the following three dimensions: Activity and performance, fans and content, and management and organization. Analogously, we consider three different user groups in our SportsTech Matrix: (i) Athletes, (ii) consumers, and (iii) management. These user groups are both exhaustive and mutually exclusive, that is, any user in sports belongs to one of these three user groups. The user angle captures the group of users that benefits from a certain sportstech solution.[19] It is important to note that these users are mutually exclusive even though one and the same person can be an athlete and a consumer and a manager in the realm of sports. However, in our matrix logic, a person can only represent one of these user groups at a time. At the same time, a sportstech solution will typically only address that user in one of the three user group roles. There are certainly solutions that target, for example, both athletes and consumers, however, they typically have different features for each group. We describe the three user groups below.

Athletes. This user group includes anyone who performs sports, no matter if it is on a professional, amateur, or even purely recreational level. It is not limited to any time period (e.g., one could differentiate before, during, or after an activity), but basically spans the entire life of an athlete. Typical applications where sportstech can provide value to athletes include training, preparation, skills, performance, recovery, injury (prevention), motivation, etc. Typical offerings include equipment, data trackers and (advanced) analytics, wearables, software applications, etc., but also solutions to find other players or venues and coordinate joint activities (cf. Malhotra, 2019).

[18]The framework has been continuously refined over the past three years; it received notable revision in 2019 based on feedback and insights from SportsTechDB, a global sportstech database that provides market intelligence on the sportstech industry. In a similar approach, Agarwal and Sanon (2016, p. 1), suggest "a taxonomy of 12 different categories of companies that collectively constitute 'Sports Tech'," based on the clustering of 400 private companies in this field.
[19]A solution can be any product, service, etc.

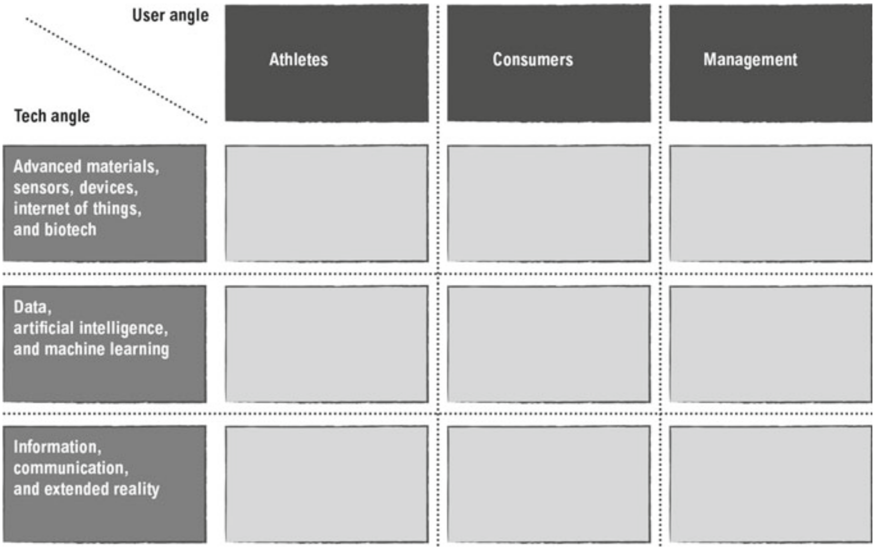

Fig. 2 SportsTech matrix

Fig. 3 SportsTech framework (Malhotra, 2019)

Consumers. This user group includes anyone who consumes sports, which encompasses all possible ways of engaging with a sport without performing the sport oneself. Basically, it is about how fans interact with sports. For sportstech, the core proposition for this user group is the provision of access to sports content (e.g., broadcasting and media), which requires capturing, processing, and presenting the required information. It is not limited to the pure provision of content as it also includes data, analytics, and insights. Further, it includes means of fan engagement such as (social) platforms and networks that allow sports consumers to engage with athletes, teams, brands, etc., to build and manage relations (cf. Penkert, 2017).

Management. This user group comprises anyone who has any management or organizational role in the realm of sports. It ranges from sports executives who lead professional clubs to managers of much smaller sports facilities or any other sort of institution. This may include the management of associations, leagues, clubs, and teams. It may also include the management of events, venues, facilities, ticketing platforms, marketplaces, etc. (cf. Penkert, 2019). Beyond these more organizationally focused aspects, the management user group also contains all aspects of sport governance that relate to defining rules and regulation or any other boundary condition in the context of sports. In our SportsTech Matrix, any sportstech solution that is not focused on the athlete or the consumer, addresses this user group.

4.2 Tech Angle

The tech angle considers three different categories of technology in sportstech: (i) Advanced materials, sensors, devices, internet of things, and biotech, (ii) data, artificial intelligence, and machine learning, and (iii) information, communication, and extended reality.[20]

Our categorization results from a thorough evaluation of existing technology classifications. It is important to note that classifications, categorizations, and taxonomies for technologies are generally scarce, particularly from an industry-agnostic point of view. There appears to be no universal or generally accepted approach to divide technologies into different categories (Ellis et al., 2016). Existing classifications are typically limited to specific areas of technology such as information technology (cf. Fiedler, Grover, & Teng, 1996; Zigurs & Buckland, 1998). By comparison, a rather technical classification comes from an European Commission-funded research project that identified systems, sensors, devices, and actuators as relevant technology types in a medical setting (Farseeing, 2013). Ho and Lee (2015) developed a typology of technological change with four different innovation types: Incremental, modular, architectural, and discontinuous. Khalil (2000) has defined six categories to structure technology: new, old, medium, high, low, and appropriate. Similarly, technologies and innovation can be grouped in different levels such as incremental vs. radical (cf. Norman & Verganti, 2014) or exploitative vs. explorative (cf. O'Reilly & Tushman, 2013).

[20]Providing an exhaustive and mutually exclusive tech angle is difficult given the constant trade-off between increasing the number of categories (which would render the matrix less useful) and maintaining mutual exclusiveness. We consider these three categories reasonably exhaustive; that is, they allow for a classification of the technologies that are relevant in sportstech. We acknowledge that some sportstech solutions may belong to more than one technology category (e.g., a sportstech solution could consist of data capturing sensors and machine learning algorithms for data processing) in our SportsTech Matrix. In such cases, we would classify the solution in one category based on its core technology.

In the context of sports, exhaustive technology classifications are also scarce. MarketsandMarkets (2019) consider four technology categories in the sportstech market: Device, smart stadium, esports, and sports analytics. The Australian Sports Technologies Network (ASTN) follows another set of four technology categories: (i) Advanced materials (e.g., fibers/textiles; composites; coatings, adhesives, elastomers), (ii) sensors and devices (e.g., advanced manufacturing; industry 4.0; IoT electronics), (iii) medical, health, and biotech (e.g., biomechanics; sleep and recovery; nutrition/ethical/nutraceuticals), and (iv) information and communication (e.g., mobile/online; big data/analytics; VR/AR/betting/esports) (Australian Sports Technologies Network, 2020). In addition, there are many similar structures of technology categorizations developed by various institutions such as sportstech accelerator and incubator programs. They often reflect similar technology categories like AR/VR, IoT, data analytics, wearable tech, and/or categories like fan engagement, sports performance and coaching, smart stadium, esports, or fantasy sports (cf. Colosseum, 2019; HYPE, 2020; leAD, 2020; SportsTechIreland, 2020; Wylab, 2020).

We find that all these classifications, typologies, categorizations, etc., have their merits, however, none of them is necessarily suitable to structure technologies in the realm of sports. Generalizable technology classifications appear to be rather difficult, if not impossible, to apply. This is partly because they do not rely on a set of general criteria defined in the realm of technology. Therefore, we contribute to closing this gap by providing a categorization of technologies that is useful in the context of sports. The consideration of technology categories is mostly focused on emerging and frontier technologies. However, it also includes other technologies that have the potential to play a major role in the future of sportstech (see Fig. 4).

Advanced materials, sensors, devices, internet of things, and biotech. This technology category is mostly about physical technologies (e.g., hardware). It includes technologies such as robotics, sensors, fibers, textiles, coatings, composites, etc. Many of these technologies play a key role in capturing data.

Advanced materials, sensors, devices, internet of things, and biotech	• Advanced/new materials • Composites • Coatings/adhesives/sealants/ elastomers • Fibers/textiles • Wearables	• Advanced manufacturing • Digital fabrication • 3D printing • Robotics • Automation • Internet of things	• Sensors • Smart dust • Chips • Near-field communication • Drones • Biotech
Data, artificial intelligence, and machine learning	• Big data • Synthetic data • Cloud • (Advanced) analytics • Artificial intelligence • Machine learning	• Blockchain • Decentralized web • Quantum computing • Cognitive computing • Computer vision	
Information, communication, and extended reality	• Augmented reality • Virtual reality • Mixed reality • Mobile • 5G	• Applications • Voice • Audio • Bots	

Fig. 4 Tech angle categories and exemplary technologies

Data, artificial intelligence, and machine learning. This technology category is concerned with data handling and processing. It includes technologies in the realm of big data, advanced analytics, artificial intelligence, machine learning, etc.

Information, communication, and extended reality. This technology category is about human interaction. It plays a particularly important role in sportstech (e.g., fan engagement) with technologies such as AR/VR/MR, voice, or mobile technologies in general.

4.3 How to Use the SportsTech Matrix

The SportsTech Matrix can be used by both researchers and practitioners. Researchers can use the SportsTech Matrix to guide their investigation of the intersection between sports and technology. For example, the SportsTech Matrix can help to structure thinking and to identify potential "white spots" that require examination. One potential white spot could be a lack of research on management. While athletes and consumers have received at least some academic attention in sportstech research, the management user group has mostly been neglected. A promising next step in research would be to map existent research on the SportsTech Matrix and explain any research areas that might emerge. This would reveal untreated or less researched phenomena and it would help to navigate industry-leading research in sportstech, which is still a challenge (Bertram & Mabbott, 2019). Further, researchers could use the SportsTech Matrix to identify promising ways to further integrate "theories from related disciplines including economics, engineering, and medicine" (Ratten, 2019, p. 2). This could be particularly useful along the tech angle categories of the matrix, as the application of research from other disciplines could lead to additional advancements in the use of technology in sports (cf. Ratten, 2019).

Practitioners can use the SportsTech Matrix in many ways, too; we will outline a few use cases here. First, the individual groups of the user angle themselves can use the matrix. Athletes could systematically assess which technologies they are already using and in which areas they could benefit from additional use of technology. For example, considering the three categories of the tech angle, an athlete might already use sensors to capture biometrical data, but they might lack the technological solutions in terms of data processing to make the best use of that data. Similarly, management could think about how to connect the individual categories of the tech angle to maximize value. For example, how can the technologies in use be best leveraged to improve performance: by capturing the most relevant data, providing valuable insights to coaching staff through improved data processing, or communicating interesting information to consumers to improve the fan experience? Consumers, in turn, are the least likely group to actively use the matrix; however, they could theoretically consider how they want to engage with athletes and sports and chose technology-enabled sports content accordingly.

Second, the SportsTech Matrix can be used by sportstech ventures and startups to develop a better understanding of the sportstech landscape and derive what need is addressed by their solution. To start, the SportsTech Matrix can serve as a reflection tool to choose the right business model. A wide range of viable business models can be observed in sportstech: B2B, B2C, B2B2C, peer-to-peer, SaaS, marketplaces, platforms, eCommerce, data licensing, and so on. It is important to carefully consider different business models as they might significantly affect the scalability of the venture (cf. Lorenzo, Kawalek, & Wharton, 2018). Thus, sportstech ventures should carefully ask themselves which users they are targeting, and which technologies can best help them in that endeavor.[21] Another important use case for sportstech ventures and startups is examining the sportstech ecosystem. It consists of startups, accelerator and incubator programs, investors, events and awards, innovation hubs and labs, and many other initiatives and representatives. Looking at sportstech from an ecosystem perspective has many benefits including, but not limited to, the following: adapting strategies and business functions to opportunities and threats of emerging trends; gaining access to networks, identifying new customers, and exploiting new data sources by plugging into the ecosystem and the existing external capabilities; and benefiting from integration with the ecosystem through open, dynamic, and real-time interfaces (e.g., integrate payment or advertising solutions) to improve own products and services (Desmet, Maerkedahl, & Shi, 2017). In addition, ecosystem perspectives can be used to represent "resource flows within, in and out of a given system" (Despeisse, Ball, & Evans, 2013, p. 565). The SportsTech Matrix can facilitate the identification of relevant ecosystems in sportstech. For example, startups could identify technology ecosystems along the tech angle such as the blockchain ecosystem (e.g., Dhillon, Metcalf, & Hooper, 2017).

Third, investors could use the SportsTech Matrix to strategically invest and build a well thought out and better balanced sportstech portfolio. So far, if we consider the user angle, the majority of funding has gone into solutions for the consumer. Between 2014 and 2019, "51% of invested dollars went to [the] 'fans & content' sector" (Penkert & Malhotra, 2019, p. 11). The SportsTech Matrix will not answer the question of where to invest money, but it helps to get a better overview and identify opportunities for investments. For example, investors could analyze funding activity along the tech angle of the SportsTech Matrix and consider an investment portfolio that focuses on a certain type of technology that might benefit all three user groups in sportstech.

5 Summary and Conclusion

The sportstech industry has grown rapidly and is expected to continue this growth for the foreseeable future. This should not only lead to improved conditions for the different user groups in sports and sportstech (athletes, consumers, and

[21]It is worth mentioning that this not only applies to startups as business models are "essential to every successful organization, whether it's a new venture or an established player" (Magretta, 2002, p. 87).

management), but also attract large corporates, startups, and institutional investors to become more active in the field (Bertram & Mabbott, 2019; Penkert & Malhotra, 2019). However, as this emerging industry is taking shape it could benefit from more structure. This is why we have proposed a sportstech taxonomy consisting of a general definition of sportstech and the SportsTech Matrix—a 3×3 grid along the user angle and the tech angle. Our SportsTech Matrix shows how different types of technologies provide solutions to different user groups in the realm of sports.

The taxonomy should provide a structure for the field and a common understanding. We aim to support both researchers and practitioners in the realm of sportstech to better handle the complexity of the sportstech industry and guide their activities at the intersection between sports business and technology going forward. Stronger ties between industrial and academic research could combine economics and engineering in the interest of sport. Therefore, it would be promising to initiate more research that is transdisciplinary and holistic in its approach.

True to the motto "all models are wrong, but some are useful," we hope that you find our taxonomy useful and a good starting point for any endeavors in sportstech.[22]

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How Thesis Driven Innovation Radars Could Benefit the Sports Industry

Sanjay Sarma, Brian Subirana, and Nicolas Frevel

Abstract

In this chapter, Sarma, Subirana, and Frevel look at trend and innovation radars, in general, and discuss how sports organizations and their management can benefit from a systematic approach to handling emerging technologies and innovations. They explain their understanding of a "corporate thesis," which is required to steer an organization to long-term success given seemingly unlimited opportunities offered by new technologies under the constraint of limited resources. To respond to overwhelming amounts of news, innovations, and disruptions, they make the case for Thesis Driven Innovation Radars and demonstrate their application in the sports industry.

news (n.)

late 14c., "new things," plural of new (n.) "new thing," from new (adj.); after French nouvelles, used in Bible translations to render Medieval Latin nova (neuter plural) "news," literally "new things." Sometimes still regarded as plural, 17c.–19c. Meaning "tidings" is early 15c. Meaning "radio or television program presenting current events" is from 1923. Bad news "unpleasant person or situation" is from 1926. Expression no news, good news can be traced to 1640s. Expression news to me is from 1889. And, no, it's not an acronym.

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The News in the Virginia city Newport News is said to derive from the name of one of its founders, William Newce.

Source: Etymology Online.

1 Introduction

The sports industry is flourishing. This is because sports is both a recreational activity and an entertainment product. In the following chapters, our colleagues will describe many interesting applications of technologies in the world of sports and what the future of sports might look like. Not only will these technologies open up entirely new approaches for how athletes train and compete, they will also change the fan experience. However, while these rapid changes provide opportunities, they are also cause of concern for executives in the world of sports. How can sports organizations avoid getting overwhelmed by new technologies? How can they balance the constant fear of missing out on a great opportunity while being prudent with resources? What executives need are tools that help them steer their organizations in these highly dynamic times. We hope that the concept of a Thesis Driven Innovation Radar (TDIR) will be a helpful tool for managers to cope with the challenges of these new realities and reach the full potential of their sports organizations.

In this chapter, we will discuss how sports organizations can benefit from a systematic approach to handling new technologies and innovations. To do so, we will make the case for Thesis Driven Innovation Radars, before providing a brief reminder on why the pace of change is not an illusion. We will then explain our understanding of a "corporate thesis" and look at trend and innovation radars, in general, before focusing on their application (or non-application) in the sports industry.

2 The Case for Thesis Driven Innovation Radars

It happens every day. A leader or board member of an organization sees an article in the news talking about how some new technological trends might be used in their industry. Blockchain in healthcare. Drones in logistics. Machine learning in retail. Robots in hospitality. Electrification in transportation. CRISPR in pharma. Technology X in industry Y.

So begins the hot potato drill. The leader forwards the email to someone vaguely knowledgeable or responsible with a what-are-we-doing-about-this: a CTO, a CIO, or a technology lead. That person forwards it to someone else, and so on down the chain. The drill often ends in a couple of ways: Either the potato cools down and is forgotten, or an obscure project somewhere is dusted off and elevated to the leader as proof that the organization was not caught off guard.

There is an alternative, more promising way. It involves actually digesting new information. We call this approach Thesis Driven Innovation Radars (TDIRs)[1] and we describe it here. Rather than reacting to each new incoming missile of information, TDIRs enable a deliberate, thoughtful, collaborative, and constructive approach to innovation in the face of news from the outside world. Some can be ignored. Some should be. Others portend something to keep an eye on for the future.

3 The Pace of Change Isn't an Illusion

> We must continue to keep up with the fast pace of change in our current world. Flexibility is a necessity […]. If we do not address these challenges here and now we will be hit by them very soon. If we do not drive these changes ourselves, others will drive us to them. We want to be the leaders of change in sport, not the object of change. The time for change is now.
>
> Thomas Bach[2]

Technological progress seems to be more rapid today than it was even a decade ago. Is this merely perception, or is it real? The numbers show that the pace of change has indeed accelerated tremendously in recent years—whether it is patents filed (see Fig. 1), businesses disrupted, venture investments, or the changing nature of jobs.

There are many reasons for this acceleration, but three key trends are feeding off each other. First, as new technologies are created, the number of combinations of possibilities exponentially increases. The intersection of robotics and vehicles yields self-driving cars. The intersection of the internet and music yields products such as iTunes. The intersection of the internet and photovoltaic power generation on rooftops is driving the smart grid. The intersection of genetics and big data is driving pharmacogenetics. And low earth orbit satellites launched by the burgeoning commercial space industry may well lead to new universal internet access. No sector is immune to this domino effect of creativity.

A second trend is the massive democratization of innovation. No longer is the latest new idea the preserve of a few institutions and companies in the US or Western Europe. Instead, innovators small and large from across the globe feel empowered to develop new ideas and to scale them rapidly. Technology, talent, and funding are global. Whether it is Uber, GrabCab, or Didi Chuxing in the mobility-as-a-service space, or Amazon, Alibaba, or Flipcart in the online retail space, ideas are exponentiating at a very rapid pace from all corners.

A third trend is a changing society. Many of the rules that were taken for granted in the twentieth century are up in the air in the twenty-first century. Why buy power from the grid if you can generate your own power? Why purchase a car when you

[1] Sarma and Subirana (2018).

[2] Thomas Bach, President of the International Olympic Committee, at the Opening Ceremony of the Extraordinary Session in 2014 in Monte Carlo.

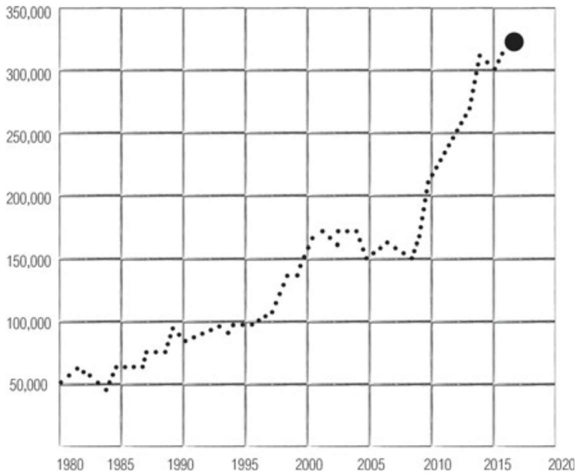


Fig. 1 USPTO utility patents issued per fiscal year (with projection for FY2017). Courtesy of dennis crouch

can use Uber or a rideshare bicycle? Why go to the grocery store when you can shop online? Why get a regular job when you can earn a living on UpWork? Why rent an office when you can co-work at WeWork? Why rent a hotel room when you can AirBnB? Why take a train when you can Rdvouz?

The sports industry is facing the same trends and changes, and technology is the main driving force. Sportstech (or sports technology) is affecting much of the sphere of sports—from how the sport is played all the way to how it is enjoyed by the global audience.[3] The quantified athlete is no longer fiction and fans taking the athletes' perspective through virtual reality is already possible. The many disruptive forces provide not only challenges for the sports industry, but also opportunities for innovation and creativity.[4] Recent industry growth and investment in sportstech are indications. For example, in Europe, this investment has increased by 27% from EUR 286 million in 2017 to EUR 364 million in 2018.[5] At the same time, the average ticket size in each funding round has significantly increased, a clear sign of a maturing market.

4 The Corporate Thesis as a Theory of the Future

Before we dive into the world of tech and innovation radars, we will first discuss the notion of having a corporate thesis, which aims to steer the organization toward long-term success. This is a crucial step before implementing a radar to provide strategic direction.

[3] cf. Schmidt, et al. (2019).
[4] Ruggiero (2017).
[5] Penkert and Malhotra (2019).

Every company likely has a thesis[6]: a theory of where the world, the sector, and the ecosystem are going, i.e., a theory of the future. The thesis, written or not, leads to a mission, a vision, and a strategy. And the strategy, in turn, leads to a roadmap. In 2007, Michael Watkins described strategy in a Harvard Business Review article:

> A good strategy provides a clear roadmap, consisting of a set of guiding principles or rules, that defines the actions people in the business should take (and not take) and the things they should prioritize (and not prioritize) to achieve desired goals.[7]

But there are roadmaps and there are roadmaps. In the twentieth century, the problem was that roadmaps were usually linear and somewhat inflexible. In 1998, the Chairman of Motorola, Robert Galvin, wrote about how companies like his and Intel had developed roadmaps over the decades:

> … [to provide] an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of change in that field. Roadmaps can comprise statements of theories and trends, the formulation of models, identification of linkages among and within sciences, identification of discontinuities and knowledge voids, and interpretation of investigations and experiments. Roadmaps can also include the identification of instruments needed to solve problems, as well as graphs, charts, and showstoppers.[8]

Ironically, Motorola and Intel's roadmaps seem to have fixated on the next telecom standard or the next feature size for fabrication; in the process, both missed the smart phone revolution. Today, Motorola is a shadow of its former self and Intel is still playing catch up to ARM.

Because things are changing quickly, theses and roadmaps need to be malleable. As Field Marshall Moltke said during the German Unification Wars, "No plan survives contact with the enemy." But planning, or roadmapping, is important. To quote another military leader, Dwight Eisenhower: "Plans are worthless, but planning is everything." What is needed, therefore, are a corporate thesis and a roadmap, but flexible and dynamic ones.

Consider Netflix in the middle of the aughts. While they were secure in their DVD-by-mail business, they probably had a thesis regarding streaming video and a roadmap to shift over. They started doing so in 2007, but by then had probably begun to realize that content was king. They started developing content in 2012; around that time, they likely adjusted their thesis by utilizing their ability to predict what users wanted to watch and finetuned content accordingly. This seemed to be playing out in 2017 with *Bright*, Netflix's first blockbuster movie.[9] In other words, Netflix was able to jump from mail to streaming to content creation to content design based on insights from big data, constantly adapting to changes in the world, sector, and ecosystem around them.

[6] In strict terms, a hypothesis, not a thesis.
[7] Watkins (2007).
[8] Galvin (1998).
[9] Cheng (2017).

Just like for Motorola, Intel, and Netflix, having a thesis is equally important in the world of sports, and great examples do already exist. Let's consider a scene from the movie *Moneyball*:

> When asked what the Oakland Ahtletics' (A's) problem was, the scouts argue that their problem was to replace players that had left the team. They needed to replace Jason Giambi's 38 home runs, 120 runs batted in, and 47 doubles.[10] All scouts were clear that they had understood the organization's problem and knew which strategy the A's had to follow. They were utterly wrong. "The problem we're trying to solve is that there are rich teams and there are poor teams. Then there's fifty feet of crap, and then there's us. It's an unfair game," explains Oakland A's General Manager Billy Beane.

What the A's needed was a thesis that would help them compete against richer teams. We all know what happened—their thesis was a low budget team could compete if they took a highly quantitative approach to manage the organization. Consequently, the strategy they developed from this thesis was to identify and acquire undervalued players that scored high on undervalued skills.[11] Following this approach, the A's were able to gain a competitive edge and clinch the American League West title in 2002. Their corporate thesis helped them to steer the organization toward long-term success. This is not an isolated case; we have seen the same story with the data-driven transformation of the Houston Astros and their neighbors, the Houston Rockets. The Rockets' strategy had a lasting effect on the game of basketball; the data-driven focus on improving three-point shots made them one of the best teams in the league.

These examples are great—Netflix and the A's got their theses right and enjoyed great success. But the question that is probably keeping managers up at night remains: How does an organization get to a good thesis? One promising way is to generate a thesis from scenarios, which we will demonstrate presently.

There has been much work on scenario planning over the last four decades, but not a great deal of agreement on the precise definition of the term. Rather than entering a semantic quagmire, we will simply go with the following definition: Scenarios are future states of the ecosystem. Building out scenarios is an act of futurism—pragmatism tempered by realism. The great Roy Amara quote is a testament to how difficult scenario planning is, especially for organizations that will be largely affected by technology:

> "We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run."

Netflix probably had a scenario in mind about the rate of growth and penetration of the internet and about streaming video. It seems obvious now, but it was not so obvious then. Companies are well advised to come up with a number of scenarios about the world they operate in.

[10] Santasiere (2019).

[11] At the time, high on-base and slugging percentages were undervalued skills that now receive much higher relevance thanks to the success of the A's.

A thesis, then, is the answer to these scenarios. Netflix's thesis was likely along the following lines: The unit economics on DVD-by-mail are not in our favor. We will likely need to start throttling and/or increasing prices. Meanwhile, internet penetration is taking off. Let's start the hard process of moving customers over. This was the painful but prophetic roadmap that Reed Hastings put Netflix on; in 2011, he paid a significant price when they lost their deal with Starz, they had a backlash from customers and the stock tanked. And yet, their thesis held up and here we are in 2020 celebrating what seems obvious in hindsight. Likewise, the Oakland A's not only met resistance within their own organization—hostile scouts and a coach unwilling to adjust his lineup to the new strategy—but they also had to stay the course when their approach initially did not lead to desired results on the field.

5 The Trend Radar as an Indicator of the Future

Before looking at the interplay of corporate thesis and trend radars, we very briefly want to introduce the concept of trend radars. There are numerous excellent examples of technology and trend radars available freely on the world wide web. Many are applicable to many industries and capture ideas, memes, and general fronts in industry, business, society, and economics. Some are more specific and focus on a particular industry such as logistics[12] or insurance.[13] They are excellent indicators, and depending on the publisher, can provide thoughtful, carefully compiled information about what is to come. They also provide hints of applications for the future. Many of these trend radars are compiled by companies as a display, with justification, of thought leadership.

RADAR

The term RADAR was coined in 1940 by the United States Navy as an acronym for RAdio Detection And Ranging [1][2] or RAdio Direction And Ranging.

Source: Wikipedia.

The features of trend radars are fairly standard. Concentric circles denote time horizons: short-, medium-, and long-term horizons or one, three, five, and ten year horizons. This corresponds to the range feature of our typical conception of a radar. The sectors of the circle are usually assigned to technology trends, with some semblance of adjacency between neighboring sectors: blockchain, for example, may be next to quantum computing. This corresponds to our metaphor of direction in radars.

[12] DHL. (2019).
[13] Munich RE. (2018).

But, by definition, these radars are fit for external consumption and unlikely to indicate secret projects or innovation activities, which must be guarded more closely. In this sense, these trend radars are what we call generic radars. We encourage a careful perusal of available generic radars, both sector-specific and industry-wide, because they are grist for the mill that we describe next.

6 The Interplay of Thesis and Radar

Now that we have separately seen the benefits of corporate theses and trend radars, it is time to look at their powerful interplay. Remember our leader from the beginning of this chapter who forwarded the hot potato email that cascades through the organization? The leader is justified in being wary and taking the new information seriously. The entire chain of events is entirely understandable. What is missing is a way to absorb and react to information—something that is needed today, but perhaps wasn't as important even a decade ago.

More than ever before, theses need to be created with peripheral vision. In today's environment, it is often not clear who the competition is. Much has been written about disruptive and other, more radical, forms of innovation. The major automobile companies probably saw each other as competition but were sideswiped by a mobility platform: Uber. Motorola was focused on Nokia, and perhaps Blackberry, but was blindsided by a computer company: Apple. Intel was focused on AMD for computer chips but was caught off guard by a low-power chip producer that immediately recognized the potential of mobile devices: ARM. A brittle roadmap is destined for trouble. A company needs a solid roadmap and a solid strategy derived from not one, but several theses that, in turn, are based on a variety of scenarios; they need a primary thesis and a few based on alternative scenarios.

Meanwhile, a radar without a thesis makes the spate of information difficult to digest. Combined with a thesis, a radar suddenly becomes useful. Now a piece of news is used to confirm and refine a particular thesis, to change or modify it, or more importantly, to discard the piece of the news. The key insight here is that most news needs to be discarded—the science is to figure out the exceptions. Or, in the words of Michael E. Porter:

> The essence of strategy is choosing what not to do. Strategy is about making choices, trade-offs; it's about deliberately choosing to be different.

Having a thesis is the foundation. The thesis then leads to a strategy and a roadmap of actions. The roadmap may have placeholders—missing pieces to look out for, based on an expectation that they will pop up in the ecosystem: A new battery technology with the right energy density, a display with the right resolution, or a drone with the necessary range. You can't find what you are looking for if you don't know you are looking for it! This is what we call "informed serendipity."

To increase the chances of informed serendipity, one needs to stay informed. New information can come from a variety of sources including patent filings, FCC[14] filings, research papers, random (non-proprietary) intelligence, conversations with partners and vendors, and from a thousand other places. The goal is to develop the antennae to seek the information that matters.

A great example of the thesis and radar concept comes from the history of the iPod. A photograph of the prototype of the iPod is shown in Fig. 2. Apple had already introduced iTunes, the jukebox in the sky. And, they had developed a thesis for a product that they called the iPod. But they were missing one piece of their roadmap: a disk drive small enough but with enough storage to enable their vision. Their innovation radar was now not randomly screening technology and innovations, but specifically trying to detect a solution for a small disk drive. The problem was solved when Steve Jobs' hardware guru, Jon Rubenstein, found that Toshiba had developed a disk drive that they did not know what to do with. Things clicked, and the thesis went into play.

This is what we call a Thesis Driven Innovation Radar (TDIR). Using a TDIR helps your organization become the best equipped for the future and to avoid surprises from disruptions and radical innovations as well as possible—or it might even enable you to become the aggressor. The TDIR helps ensure a resource-efficient approach, avoiding lengthy and expensive technology evaluations.

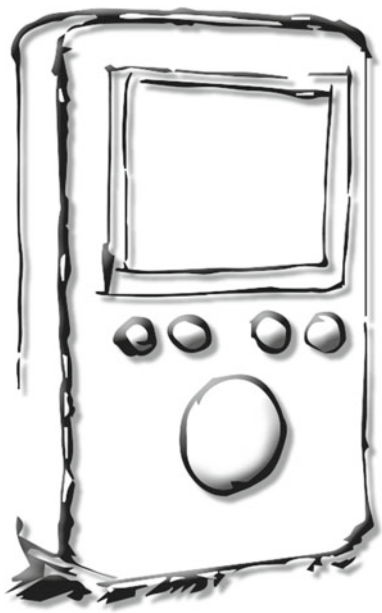
7 The Role of TDIRs in the Sports Industry

While the sports industry is at the forefront of technology on some fronts, it lags on others. The majority of sports organizations do not have concrete innovation strategies in place,[15] let alone a thesis. A thesis is also a motivational tool which helps recruit talent. Adequate people strategies are also not yet in place and skill gaps exist.[16]

The hot potato drill we have described earlier is probably an everyday phenomenon in many sports organizations. A seemingly unlimited number of technologies—from startups and large corporations—land on sports executives' desks every day, each trying to convince them why their VR/AR-, AI-, blockchain–, robotics- or any other technologically advanced solution will help the sports organization to be more successful in the future. The sports leader—who might have limited knowledge of or experience with these technologies—is often overwhelmed and will forward the matter to someone who is more knowledgeable in this particular area. Only rarely, is the result of this process a successful endeavor for the organization.

[14]Federal Communications Commission (FCC).
[15]PwC. (2019).
[16]Schmidt, et al. (2019).

Fig. 2 Prototype of the iPod



As the hot potato drill is a frustrating experience for everyone involved, sports organizations–just like organizations in any other industry—seek ways of better handling the constant change in their ecosystem. Their answer typically is to install a group of people in charge of solving the puzzle of technology and innovation. This group of people is sometimes a dedicated division, but more often is a loose task force that wastes significant time and energy in lengthy meetings. This is not the ideal organizational setup, but there is one decisive and even bigger problem.

The key problem for many sports organizations is that at the core of their considerations around technology and innovation, they deliberate on the wrong question. They ask how they can benefit from AR/VR, blockchain, AI, etc., and they will try to incorporate these technologies as a result of their fear of falling behind. Instead, they should start by identifying the key problems their organization is facing and then ask which technology can best help them solve that problem. And, to be clear, the answer can still be an Excel spreadsheet rather than a blockchain-based solution. Technology should never be an end in itself.

Thesis Driven Innovation Radars could possibly be the solution that sports organizations have been eagerly longing for. It means defining a theory of where the world, the sector, and the ecosystem are going (i.e., a thesis), deriving a strategy and roadmap from that thesis, and then using an innovation radar that specifically finds solutions to the organization's problems that are critical to following the roadmap and strategy. Or in Thomas Bach's words: "Sports organizations should not solely be object to change, but be the drivers of change."

8 Peloton Planning for the Future

Once companies have a Thesis Driven Innovation Radar, they have to decide which part of their plans they want to share with their suppliers and customers. In general, it is difficult, especially in the world of sports, for companies to introduce radical innovations on their own. There are many reasons why this may be the case. For example, in many sports like swimming, tennis, or football, the governing body often wants a final say or clubs may want to influence the deployment schedule. The introduction of video review has been postponed for years even when the technology was ready.

To help companies synergize innovation agendas with the rest of the industry, we developed the concept of the Peloton, a term that draws inspiration from bicycle road races such as the Tour de France. Riders naturally tend to form coopetitive clusters. Companies and technologies, in our view, form similar clusters; coordinating in a coopetitive way enables convergence on technology roadmap milestones and standards.[17] During the development of RFID standards, we, two of the authors, and graduate student Vineet Thuvara, developed a collaboration tool called the Peloton tool for facilitating collaboration across industry. We put the tool into practice with vendors and end-users.[18] We used this process to drive convergence pre-competitively for standards and milestones.

Using the Peloton tool, we feel planning for the future of technology can be done by putting sports at the forefront and integrating other applications around it. This already happens in the shoe industry, where sneakers lead the way for other more casual shoes, and in racing, where many innovations are first tested on the racing track.

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Physical Technologies

Robotics, Automation, and the Future of Sports

Josh Siegel and Daniel Morris

Abstract

This chapter explores the growing influence of robotics and automation on sports and potential resultant future states. In this chapter, Siegel and Morris describe advances leading to broader deployment of robotics and automation and envision how these technologies may lead to new models for spectator experience by increasing engagement and interactivity. Next, they consider how robotics and automation create opportunities for improved athlete training and detail how robotics and automation have augmented sports by allowing new athletes to compete, creating new sports, and providing a playing field for intellectual athletes. Finally, they envision possible future evolutions of sports leveraging robotic advances and present a case study on how robotics might impact motorsport, closing by considering potential non-technical challenges and risks in inviting robots into sport.

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1 The Opportunity for Robots in Sports and Components of Robotics and Automation

Sports are games of skill that test the limits of the human body, mind, and spirit for the enjoyment of participants, supporters, and spectators. Organized sports push competitors to their limits, with rules creating literal and figurative goalposts against which to measure one's mettle within rigorous proving-grounds.

Athletes may excel in strength, endurance, quick reactions, precise control, or strategic planning. Common traits include competitiveness and a desire to outsmart, outwit, or otherwise outperform in order to become the best. Robotics and automation can help all athletes—and supporting individuals—make the most of their participation by improving training, scoring, and gameplay, among other areas.

Spectators play crucial roles from motivating athletes from cheering to funding through ticket sales and advertising consumption. Sports gain prominence through popularity, and great effort is expended on spectators, from building enormous stadiums to cultivating a fully immersive future. Robotics and automation help create a better experience, bringing about additional engagement and funding to enrich sports. In this chapter, we consider how these technologies bring about change for players, spectators, and sports writ large.

Sports and technology are intertwined, with advances in robotics and automation poised to bring about dramatic changes. The fundamental robotic capabilities of perception, planning, control, manipulation, and locomotion are the same skills on which human athletes rely. Their physical or virtual automation presents opportunities for both structured games such as chess, with known rules and allowable moves, and unstructured competitions like football, where scoring mechanics are known but allowable states and their transitions are fluid.

Robotics and automation address the means by which robots and humans interact with the world, including perception, planning, control, locomotion, and manipulation. Perception is the science of observing a system's internal and external states (position, environment, and context) using transducers, sensors, signal processing, and data fusion techniques. Resulting data inform a comprehensive state-space model—the human analog of which is seeing a basketball, a net, and painted lines on a wooden floor to intuit the context that a player is on a basketball court and oriented a particular way.

Planning is related to decision-making and allows systems to work toward small-scale and larger goals, for example advancing a ball down a field versus scoring a goal. Planning targets a particular outcome and determines the optimal action (sequence) to attain that goal. Actions may be flexibly composed (there may be multiple ways to attain a goal with the optimal approach changing based on perception).

Control is the method by which a robotic system executes planned actions and ensures that the process evolves according to expectations when perturbed. Control systems modulate actuators, which are robotic elements affecting the system's state (position, orientation, and velocity). A human analog for control is holding one's arm in position during an arm-wrestling match, even as the opponent applies varying force.

Locomotion and manipulation are the means through which robots traverse and affect the world. Articulated hands, arms, wheels, and treads are common devices, with softer, lighter, more flexible, or with grippier materials imbuing robots with capabilities that rival or exceed those of humans. Manipulation and locomotion are how players hold balls and move them down the field.

In aggregate, these capabilities facilitate partial or complete automation of complex systems. Robotics and automation are already used in sports to facilitate training exercises, to capture new camera angles, and to augment human capabilities. In the future, robotics and automation may further enhance, augment, or replace more-traditional sports.

Robotics is well suited to competition-based innovation, whether human-inspired or task-based (Nardi et al. 2016). Already, DeepBlue's automation trounced humans in intellectual competitions (Campbell et al. 2002; Frias and Triviño 2016). More recently, AlphaGo took humans to task in a complex mental game (Silver et al. 2017). However, robotics and automation are equally capable of leading innovation in physical sports. Perception, planning, and control apply to tasks involving physical prowess and present opportunities for technical development. By 2050, humanoid robots may be able to compete with–and best–FIFA players in a game known for speed and dexterity (Burkhard et al. 2002).

The remainder of this chapter explores robotics and automation in sports and what these capabilities may mean for the future. We begin by considering why robotics and automation are spreading within sports. Next, we envision how robotic technologies may lead to new models for spectator experience of, and immersion in, sports, by inviting spectators to participate and experience the thrill firsthand. We continue by exploring training, and how a host of technologies will enhance athlete performance using richer analytics and virtual competitors. We then examine how robotics augment sports by allowing new classes of athletes to compete in existing sports, and how technology creates new sports wherein robotic competitors are designed by intellectual athletes. We envision future states for robotics in sports (including speculating an approximate timeline for these states, with a reference start date of 2020) and dive deep into a case study of how robotics might impact motorsport. We close by considering potential non-technical challenges in inviting robots into sports and associated risks.

2 Behind the Rise of Robotics

Advances in robotics have made its deployment tenable outside of research and development. Improvements in capabilities like sensing, connectivity, computation, algorithm design, control, and actuation have lowered costs, eased deployment, and made automation pervasive across a broad range of domains.

In sensing, low-cost, power-efficient sensors have improved our ability to instrument and measure people, equipment, and environments (Ciuti et al. 2015). High-bandwidth, low-latency, secure and efficient connectivity have made it possible to move information rapidly from sensors to remote computing environments (Siegel et al. 2017a, 2018a), in which highly parallelized processors run advanced algorithms to extract latent insights. This approach, called "pervasive sensing," captures data in bulk to discover hidden relationships without a priori hypotheses. The use of "edge computing" enables active sensors that can intelligently capture data such as cameras that track, pan, zoom, and focus on an athlete without human supervision.

Advances in artificial intelligence have expanded both the breadth and depth of robotics. Powerful visual sensing algorithms enable robust object detection and classification under real-world conditions; capabilities that required years of development can be trained in days. With open-source, standardized machine learning toolkits such as TensorFlow (Abadi et al. 2016) and PyTorch (Paszke et al. 2017), new algorithms are often distributed with executable code allowing anyone to easily develop such capabilities.

Novel architectures like the Robotic Operating System (Quigley et al. 2009) simplify the creation of robots, with commodity hardware such as the TurtleBot (Pyo et al. 2015) and low-power multi-core GPUs by companies such as NVIDIA (Ujaldón 2016) offering inexpensive and extensible platforms lowering developers' barrier to entry. Improvements in control systems and advanced multi-degree-of-freedom actuators (Salerno et al. 2016; Kaminaga et al. 2017; Kuindersma et al. 2016; Suzumori and Faudzi 2018) and biomimetic muscles (Must et al. 2015; Lee et al. 2017) allow robots to move accurately and precisely, enabling novel output possibilities. Peripheral advances including additive and distributed manufacturing, the maker movement, and high-power, high-energy batteries unlock additional potential for commoditized sports robotics.

With this perfect storm of technical capabilities and simplified development, robots have already found homes in sports. Robots indirectly help human competitors prepare or perform, for example by supporting improved training systems through richer performance data capture with drones (Munn 2016; Yasumoto 2015), or through the creation of repeatable robotic adversaries against which athletes may benchmark themselves or test their ability to respond to unpredictable scenarios at the edge of human capabilities, like intelligent pitching machines. Robotic systems help human athletes directly, augmenting their perception or physical strength—for example, exosuits may, in the coming decade, provide Paralympic competitors with additional strength, stamina, and stability (The Star Online 2016; Onose et al. 2016).

3 Super Spectators: Robotics for Fan Immersion, Engagement, and Participation

360° replays such as EyeVision (Thomas et al. 2017), which first replayed a touchdown in Super Bowl 35 (2001), point to a future of multi-view sports consumption. Ubiquitous, network-connected cameras and microphones, including body-worn, robot-controlled and drone-carried with virtual reality (Hameed and Perkis 2018) or 360° recording (Standaert and Jarvenpaa 2016) will capture a richer view of sporting events for streaming to televisions and mobile devices, with potential for angles and commentary to be customized based on user preference. This is already happening but bound to improve. Within five to ten years, artificial intelligence will automatically choose or merge camera views based on preferences, historic data, and event analysis with procedurally generated commentary (Chen 2018). Time need not flow linearly; replays from synthesized viewpoints could be requested at will or automatically superimposed over low-interest gameplay. Automated broadcast "supercuts" may be feasible in as few as five years.

Electronic sports, or esports, (Llorens 2017; Hamari and Sjöblom 2017) evolved from multiplayer video games and now center around professional athletes competing in tournaments for high prizes, viewed both online and by crowds in massive stadiums. While there has been debate on whether or not to classify them as "real sports" (Thiel and John 2018), there is increasing acceptance as they share the core aspects of competition, tournaments, and spectators that comprise other sports. Their operation in virtual environments enables esports to implement features that we can only speculate about in other sports. Live online viewing of matches is readily available on platforms such as Twitch, and increasingly on traditional broadcasts such as ESPN and BBC. Online viewing enables spectators to comment on and interact with other fans while viewing. Additionally, spectator immersion using virtual reality headsets, as well as spectator modes that give individualized global views that are not available to team players (Sullivan 2011). These global spectator modes operate with a slight delay to prevent teams from taking advantage of them. We anticipate that similar immersive modes will transition to other sports over the next decade as real-world data collection technologies advance.

Robotic simulation may finally answer fans' what-if questions. Predicting the outcome of alternate plays is of great interest in sports such as American Football to both fans and commentators. These predictions will share data-modeling characteristics with weather forecasting, combining physical models of the athletes and their environment, mental models of their reactions and goals, and incorporating numerous uncertainties, simulated play with statistical sampling may predict likely outcomes. The combination of large data collection, more powerful hardware, and simulation-based learning will make these predictions increasingly reliable over the next 10–20 years. However, a complicating factor is that the availability of these predictions in real-time to coaches may impact the actual play. These will add another layer of the strategy of out predicting the opposing team.

Simulation brings the game to the spectator and blurs boundaries between player and observer. For instance, one might play tennis with a Digital Twin of Serena Williams modeled after her performance characteristics. For five to ten years, this may be restricted to virtual and augmented reality environments, but the advance of full-scale, human form-factor robots presents the possibility of playing tennis with a physical robot that has been trained to play tennis just like Serena Williams, with a similar serve and mobility. This could be twenty to thirty years out. Less expensive ways of achieving realistic play may be through augmented reality with specialized hardware. In fifteen years, one might join the line of scrimmage on a motion-supporting platform wearing a helmet that projects the viewpoint of a player directly onto one's retina and with a haptic-supporting bodysuit so players can feel every hit. Impacts from other players of a particular play can be experienced firsthand through tactile actuators, while a VR treadmill may allow the fan to move about as though on a real field.

Fantasy sports and betting on sports are big business and drive spectator engagement with sports. Sports betting has become a sport of its own, with significant rewards for the winners and billions of dollars generated for supporting organizations. Acquiring inside information on player performance to give an edge to bets has a long history, and the future of improving betting odds may center on predictions obtained through big data and predictive simulation, or robotic competition modeled after human performance. Big data, artificial intelligence, and simulation will begin to inform betting strategies in five to ten years.

4 Robots and Automation in Training and Strategy

While spectators and bettors will benefit from simulations and analysis, the most-direct beneficiaries will be athletes, trainers, and coaches. In fifteen years, players may have their own coaching robots, capable of capturing laser scan data or otherwise estimating their pose to analyze performance in real time with superhuman perception. In thirty years, data fed back to augmented reality contact lenses could provide a rapid loop closure for feedback.

By 2050, athletes may train against humanoid robotic competitors to learn how to react against a superhuman adversary—perhaps even a statistical model of the player's own performance and typical playing style with slight improvements. In ten years, precise motion tracking could capture data from another professional athlete (Toyama et al. 2016) on an opposing team, such that players can learn by facing-off move-for-move against the best humans around. Already in the esports world, AI bots are developed to train professional players (Takahashi 2018), and robot trainers will enter an increasing number of physical sports over the next ten to twenty years.

Training robots may be humanoid or purpose-built and could emulate kicking, pitching, swinging, defense, or more. Even if they are too expensive for home use, businesses could open by 2040 to allow fans to see how they would perform when faced with a tennis pro's serve, bringing about a more realistic experience and visceral, emotional reaction than might be created with virtual reality alone.

Robots will assist and augment more than just athletes. Drones help coaches prepare their team and individual players by capturing video from new angles, or by automatically following athletes to create good television (Yasumoto 2015; Kohler 2016), to create self-promotional action videos, or to provide videographic feedback for an athlete to monitor their form (Toyoda et al. 2019). Other robots automate menial tasks that are important but uninteresting, such as collecting tennis balls (Kopacek 2009), serving as a golf caddy (Kopacek 2009), or leading tours around a sporting venue (Kopacek 2009) (similar robots may one-day usher fans to their seats). Some of this is already feasible today—and performance will improve markedly in the coming ten to twenty years. By this time, robots may act as training buddies, accompanying athletes as they train, carrying water or medical supplies; in thirty years, they may go as far as to rescue an injured athlete.

5 Enhancing and Creating Sports with Robotics

Judging errors, whether unintentional or the result of bias, may become a thing of the past with automated robotic refereeing and scoring. On the field, infrastructure such as laser curtains capable of plotting ball positions in real time and measuring its forward trajectory (O'Leary 2016; Samiuddin 2019) may be used to make better calls or to review scoring calls. These capabilities will be gradually incorporated over the next two decades as they demonstrate reliability, which will ease acceptance. Rich sensing can provide data to make judgment calls pertaining to rule violations. In ten years, ground-based or aerial robotic referees and medics may patrol the field in scenarios that might be too risky (or too fast) for human supervision and instantly detect injuries. For less-fortunate players, robots twenty years out may help improve outcomes through robot-assisted surgery or physical therapy. The delay is due in part to testing, certification, acceptance, and liability.

It is not just scoring and supervision that will change; participant eligibility may evolve. In ten to twenty years, man and machine may merge through actuator-driven augmentations or assistive technologies enhancing strength, speed, stamina, and reaction times. Exosuits (Walsh et al. 2007) exemplify how machines may allow disabled individuals, or less-competitive athletes, to participate at a high level. The Paralympics demonstrates the early stages of this and has already illustrated how rules must adapt in order to govern and, in cases, limit the use of technology to ensure fair and exciting competition.

In addition to improving upon centuries-old disciplines, robotics and automation will create new sports. Some may feature human-mimetic robots, others will use machines to augment humans' physical capabilities, while others still will use machines to extend the human mind and body. Some emergent sports are educational in nature, while others are more subtly technical.

Educational robotic sports (Johnson and Londt 2010) include the STEM-focused FIRST competition and its feeder series, the Robofest competition, (Chung et al. 2014; Chung and Cartwright 2011) and RoboCup, (Kitano et al. 1995) which develops humanoid soccer-playing robots aimed at beating human FIFA players by 2050. Technology-focused robotic sports include the DARPA (Urban) Grand Challenges (Kopacek 2009; Thrun et al. 2006; Buehler et al. 2007; Buehler et al. 2009; Guizzo and Ackerman 2015) and the DARPA Robotics Challenge (Guizzo and Ackerman 2015). More subtly technical sports include automated small-scale car racing (Karaman et al. 2017; Roscoe 2019; O'Kelly et al. 2019) and semi- and fully automated drone racing, which has been met with great spectator interest and million-dollar prizes (Gaudiosi 2016).

Some robots may emulate humans and play sports themselves. An automated slot-car racing system exceeds the performance of humans (Delbruck et al. 2015), there are robot-golfers (Kopacek 2009) and robots capable of playing basketball (Nagata 2019), ping-pong (Wang et al. 2017), or billiards, sumo wrestling, and wall-climbing (Kopacek 2009). RoboGames was the largest gathering of robotic athletes (Calkins 2011) in "traditional" sports, offering competition in soccer, basketball, weightlifting, obstacle courses, hockey, and more (Kopacek 2009), with 700+ robots from 18 countries in 2017 (RoboGames 2017). Some robo-athletes more abstractly demonstrate physical prowess, for example through fire-fighting competitions (Kopacek 2009) or skiing demonstrations (The Guardian 2018). These robot-athletes may be humanoid, vehicular, or be otherwise functionally designed, e.g., for use in aerial and underwater robotic competitions (Kopacek 2009).

The robotics revolution is extending the capabilities and reach of the human mind and body to create new sports. Witness drone racing, which allows the human mind and body to perform unlike ever before, flying through the air at unprecedented speeds with unmatched agility. Whereas G-forces, risks, and costs would have previously limited humans' abilities to compete in such a manner, commoditized hardware has made it feasible for average people to compete with one another at a grand scale.

In twenty to thirty years, it may be possible for humans to engage with advanced robots through a brain-wave interface (Tanaka et al. 2005) or a gaze-based system (Armengol Urpi 2018) to control humanoid robots as they fight to the "death." Robots may be placed in scenarios where moral hazard would limit human presence—but robo-gladiators could become wholesome fun as engineers, developers, and grand "puppeteers" strive for dominance. Improvements in sEMG signal interpretation may allow humans to control robotic prostheses (Taborri et al. 2018) or even sacrificial body doubles. By 2040, remotely communicating such signals could facilitate robot-fighting leagues where humans control evenly matched robots so that strategy and style determine the winner, rather than strength.

The spectacle would be more engaging than today's "BattleBots," as human mimicry may be more visually entertaining and relatable than a radio controller and wheeled vehicle. Of course, such engagements may one day be made purely virtual to reduce costs—though that would remove the element of risk and possibly thrill for participants and viewers alike. “VR/AR Magic,” such as fighting as a dinosaur, or battling impossibly large foes, could bring back some of the thrill for competitors and spectators alike.

6 Sports-Driven Robotic Developments

Competition is a good motivator not only for athletes but for scientists and engineers, while game rules provide structure to focus on energy and efforts. Not only will advances in robotic engineering and design improve these systems’ sporting ability, but the technical innovations will improve robotic hardware and software. The result will be systems with enhanced speed, improved responsiveness to perturbations, increased energy efficiency and lightweighting, and novel algorithm design. Software improvements will for the first fifteen years focus on tracking, prediction, and pursuit. Mechanically, there will be advances in gripping, grasping, manipulation, and locomotion such as running. In sensing, there will be innovations in robustness, fidelity, range, precision, and accuracy, and connectivity will grow to support higher-bandwidth and lower-latency. Augmented reality, even in basic form, can capture the imagination of millions, as seen through the popularity of Pokémon Go, and can be implemented at scale through mobile devices.

Humanoid robots may begin by mimicking human performance and in forty to fifty years be able to compete on the same playing field as human athletes (Kondratenko 2015). RoboCup promotes the development of AI and robotics through competitions designed to mimic human-style soccer play (Gerndt et al. 2015), and has enjoyed progress in recent years toward functional humanoid robots completing full soccer games (Gerndt et al. 2015) using human-like sensing capabilities (Gerndt et al. 2015). RoboCup is working toward compliance with full FIFA rules and comparing performance against humans by 2050 (their goal) (Gerndt et al. 2015) and may not long after, perhaps by 2060, outperform and displace humans. Already, humans have been used to train robotic algorithms. In RoboCup, soccer-playing robots walk better if trained based on motion derived from infants learning to walk (Ossmy et al. 2018).

Another example of sport driving robotics and automation innovation is sailing, an age-old enterprise that facilitated activities from Viking raids to worldwide exploration. Sailing competitions, from America’s Cup to SailGP are hotbeds for innovation with high-tech catamarans on computer-controlled foils. SailGP (2019), with a common foil-mounted catamaran for all competitors, exemplifies trends in robotics and automation. These include immersing spectators in the event with live-streamed sights and sounds from onboard cameras and microphones, annotated with technical data. Advanced materials, lightweighting and control are expanding the envelope of sailboats, enabling operation in wind speeds between four and 30 knots and achieving boat speeds up to 53 knots. New technologies will continue to evolve the boats, driving spectator engagement and challenging crews to focus on the human aspects of tactical sailing in varying conditions and winds.

Competition helps to push technologies to the masses, with new sports technologies spreading rapidly and bringing innovation into our daily lives. Commoditization of hardware and software will turn spectators into players–for example, as “average Joes” go on to become famous drone pilots or esports competitors. This democratization has potential especially in educational environments, wherein low-cost or virtualized robots can teach valuable skills to students across socioeconomic classes and geographies (Martins et al. 2015).

If we are able to build robots better meeting the needs of complex tasks, these same robots may help to automate mundane jobs and allow increased time to participate in or spectate sports in our day-to-day lives. This innovation will also create opportunities for additional mental athletes, rather than physical athletes.

7 A Case Study of Robotics and Automation in Motorsports

Racing celebrates the human desire to be first and fastest, drawing upon symbioses between humans and mechanical marvels. Motorsports are high risk and high reward, with drivers blurring lines between control and chaos.

Drivers race for the love of sport, with competition feeding an addictive passion that allows him or her to become one with a machine for the singular purpose of victory. Supporting each driver is a motivated team: engineers try to out-think world-class intellectuals. Mechanics tune cars to match evolving weather and track conditions. Crew-chiefs turn jargon, data, and intuition into performance magic. Spotters keep drivers in their literal and metaphorical lanes. Owners strive to prove that they have the resilience, mental aptitude, and resolve to manage better than anyone else. Manufacturers struggle to demonstrate that they employ the best and brightest.

Spectators watch races to witness drivers’ otherworldly finesse and reaction times, taking in a sensory symphony of sight, sound, smell, and feel, while those at home are captivated by suspense. They form emotional bonds with drivers, cars, tracks, teams, and brands by watching humans pilot a vehicle resembling their own to victory. Some fans participate in simulated racing and understand just how nuanced one’s inputs must be to consistently perform thousands of a second faster than others.

With these relationships, motorsports serves as a testbed for technologies that may impact consumer vehicles and the world writ large. The sport evolves *visibly* with the passing of time, with apparent engine and suspension changes, aerodynamic advances, and safety improvements.

Racing series embrace technology at different paces. Some standardized vehicles or limit driver aids to showcase raw human talent, others limit technology’s use to the design or operational phase, while others still embrace widespread technology adoption. Progressive series brought turbocharging, all-wheel drive, carbon fiber, aerodynamic design, semi-automatic gearboxes, mirrors, disc brakes and antilock braking, traction control, dual-overhead cams, active suspension, and radial tires to the consumer market (Edelstein 2019).

Formula 1 (F1) is an innovation-centric series that will benefit from robotics, automation, and related technologies. Sensing will generate the richer vehicle and environmental data informing real-time operation and design improvements, and connectivity will facilitate high-fidelity telemetry for remote vehicle diagnostics and strategy calls. Artificial intelligence will automate performance optimization, control unit calibration, material selection, and mechanical design. Virtual and augmented reality may improve training or provide drivers with contextual information without distraction.

Technical advances must be sensitive to tradition, competition, cultural pressures, and economic challenges. In F1, cars must remain open-wheel for the sake of tradition (and drag), drivers must drive, and the governing body and team owners emphasize profits. Drivers and spectators crave risk—"to take away the risk in car racing would take away what it means to be a race car driver," wrote Tony Kanaan after the death of a fellow racer. "You have to be a little crazy to do what we do. We're okay with that. We wouldn't have it any other way." (Kanaan 2015). At the same time, vehicle designs must be exciting, relatable to road-going vehicles, inexpensive enough to fill the grid regularly, and have visible drivers to allow spectators to relate emotionally throughout a race. Considering these needs, we present a vision for F1's use of robotics and automation in the mid- and long-term future.

The simplest robotic departure from business as usual (human-driven cars with AI-informed designs) is telepresence, with a human driver controlling a full-size car through a remote interface. In ten years, this could allow drivers to take more risks, without removing consequential costs from collisions. Teams could save the budget by eliminating non-essential team travel and competing remotely.

Another future state, fifteen years out, human drivers eliminate (initially imperfect) AI control, using models trained by (or against) humans. AI systems could compete against one another, or if the moral hazard of allowing AI to jeopardize human life is resolved, human drivers could race against AI. This opens the possibility for "spec racing" series, where either the car or the AI is held constant—so that both algorithms and design can be optimized, with the findings feeding back into human racing series.

There are other potential "blended" scenarios with AI-assisted driving in the interim, for example wherein a human driver and AI exchange control of the same vehicle—either based on timing or distance, like endurance racing, by track location, by car position, or from fan input. Forcing handoffs would retain human skill and excitement, and further the state of automated vehicle research.

Governance will play a role in balancing (perceived) risk, excitement, costs, and viewership. Standardization and homologation, for example, may reduce operating costs and allow software to become a bigger differentiator than hardware. Off-season testing rules will need to specify the appropriate use of simulation and when it is acceptable for software to be changed.

Automation will join motorsports alongside technologies such as electrification, smart materials, and active aerodynamics to create a compelling package. Vehicle design may change to adopt driver assistance systems including traction control, torque-vectoring, and active suspensions in ten years. Micro-actuators may support full-body active aerodynamics, while smart materials like electronic muscles may adapt chassis stiffness in real time in thirty. Brain HMI may allow cars to remove unsafe steering wheels and pedals and speed reaction times in twenty years, while over-the-horizon data may inform AR heads-up displays in as few as ten.

Connectivity unlocks possibilities for drivers, engineers, and fans. Drivers may use connectivity to safely remotely pilot vehicles. Engineers will capture data in real time for predictive diagnostics (Siegel et al. 2016a, b, c, 2017b, 2018b), strategy calls, or to remotely-update control modules in five years. Fans could watch live telemetry, or if the FIA allows, control vehicle performance—for example, by remotely unlocking reserve battery charge, in as few as ten years.

Vehicle-to-vehicle connectivity (Siegel et al. 2018a, c) and high-fidelity sensing may combine to form a nigh-impenetrable safety net allowing for closer, safer racing in thirty years. If collisions are imminent between human drivers, AI might prevent these collisions and sideline the cars that *would have* been involved, creating excitement, thrill, risk, and consequences without the threat of physical injury or bankruptcy. Cars drafting 10 cm apart would be engaging for viewers and maybe a reasonable compromise of allowing drivers to use their judgment to take risks without the risk of imminent death, improving spectator excitement and empathy.

The FIA will need to determine which elements are standardized to balance cost and competitiveness, including computing units or algorithms, and how much simulation, testing, and midyear adaptation is allowable. If cars are increasingly standardized, new modes of visually differentiating vehicles from one another must be created to retain spectator interest. With these changes, every stakeholder will experience future motorsports differently.

Drivers will be able to practice with more-faithful simulation than ever in five to ten years, providing feedback for crew chiefs to optimize designs efficiently with human-in-the-loop testing. Training against "super-human" AI's will push drivers to become better, while competing against high-fidelity replays or AI trained on historic data will allow drivers to see their own performance from an outsider's point of view, in VR as soon as 2025 and in AR, competing against a realistic virtual ghost, by 2040.

Comprehensive data will change the driver-crew dynamic by providing more information about potential problems and solutions, while team management will change, with strategic decisions revolving around the decision to buy automation systems or to design them in-house, and around whether to buy (and/or sell) AI training datasets in ten to twenty years. AI may similarly be used to predict future driver performance and determine a driver's potential marketing and sponsorship potential to aid negotiations—which may itself use AI to determine a "fair" price.

Race rules may evolve, leading to entirely new strategies. For example, a team may have a fixed budget for usable energy shared across cars. What if the team owner can shift pack capacity virtually from one car to another so that one driver is a shoo-into win, rather than both drivers on the team coming in second and third, respectively?

The business of AI-assisted racing will look unlike racing today. While drivers race for themselves, and team owners race for glory, racing needs spectators to be a viable business. Though electrification may eliminate the rush one gets feeling the rumble of thousands of horsepower flying by, new technology will increase motorsport's reach to remote regions by increasing streaming access and multi-media for spectators. Fans will be able to watch races with data-augmented cameras, virtual reality views, and augmented reality, showing overlays of over-the-horizon data on large tracks. The technology will exist for fans to control car settings, such as active aerodynamic features, charge-limiting, and more. Moreover, spectators may engage *more* with high-tech racing, cheering for suppliers, programmers, or even algorithms.

Robotic and automation racing innovations will drive advances in consumer vehicles, particularly for assistive technologies, engineering and simulation tools, and human-handoff capabilities. If a car can use AI to avoid a collision at 200 M.P.H. in twenty years, it should be able to avoid a collision at highway-speeds in the same timeframe.

Elements of this future state are not far off. Formula-E batteries now last a full race (Blackstock 2018). 360° cameras exist, and remote telemetry is used by many series. 5G and Dedicated Short Range Communication are bringing vehicle connectivity to the masses, and active aerodynamics are used today. Even robotic racecars exist—see RoboRace, a spec-series with standardized hardware where competition takes place in algorithm design—though speeds are (for now) slower than human drivers (Uhlemann 2016)—or the coming Indy Autonomous Challenge, a one million USD competition to complete the fastest lap around a world-famous racetrack by 2021 (Indy Autonomous Challenge 2019).

While much of the technology for this future vision exists, it will take time for motorsports to get up to speed. Slow incorporation and an incremental roadmap may be the most successful approach, for example by first automating the safety car by 2035, and then implementing higher-bandwidth, lower-latency connectivity, and finally building a connected-vehicle safety net by 2050. Moving too quickly will witness people complaining about corrupting the purity of the sport; and it could bring robotics and automation into the spotlight before technology can adequately address "corner cases" unseen in training data.

There are other considerations, as well. A driver will push boundaries and "bet the car," but it is harder to create a robot with courage without hubris. Selecting the optimal algorithm for balancing risk and reward will be a challenge in the near-term. Drivers have years of experience in reading the road and adapting control with great nuance—in part because of deductive logic and reasoning. However, artificial intelligence primarily remembers, rather than reasons—and so robotic cars will require big data to match human performance, but once the corpus of information exists, it will be possible for robo-drivers to jump into unseen tracks and perform expertly by 2045, removing some of the fun in spectating.

A significant challenge is how robotic motorsports can remain captivating to spectators with reduced "humanity" and its associated emotional relatability. At first, robots will fail and make mistakes, which is exciting for spectators. When robots get "too good" and cease to crash, will the sports lose interest? If teams adequately push boundaries, the solution is to simply go faster until algorithms no longer keep up, to continue to ride the line between control and collision. In this case, the sport itself is exciting, but perhaps no longer relatable to the human experience. One solution may be to require that robotic cars are driven by humanoid robots (Ross 2017; Brackett 2017) with expressive faces (or displays) capable of communicating emotion, or in the case that cars are driven via telepresence, that drivers appear on stage and visible to an audience.

From a business perspective, spectator demographics may change. If we remove the human limitations—geometric and otherwise—we have more freedom to tune aerodynamics, to lower the center of gravity, and to have geometries with terrible visibility and no crash structure. Cars can be lighter without safety equipment, faster cornering, and designed for raw performance rather than survivability. Perhaps future fans will be equally interested in the technology and engineering of the vehicle as they are in the strategy and the "driver.".

Robotics and automation may make racing more immersive, faster, safer, and easier for drivers to succeed in the short-term. These capabilities may even open up new racing series. However, long-term, practitioners must be careful to ensure that the sport remains relatable for spectators, exciting, and emotional, and that the technologies developed are applicable to solving problems in a broader context.

8 Challenges and Opportunities in Broader Sports Robotics

The technical elements of sports robotics are hard, but well along the way towards being "solved." Curiously, it is the human element of sports robotics that presents the biggest challenges.

People watch sports to watch human achievements and to experience the triumph of victory by proxy. At what point do robotic systems, or automated systems, cease to be human? If a human beats a robot in arm-wrestling, does it matter? What if that robot used artificial muscles—would that competition be more meaningful, more significant (Frias and Triviño 2016)?

Competitions that are most relatable to humans will have the most significant emotional responses and widest appeal. It is easy to make the case that when AI, rather than humans, is successful or fails, there is no drama, and nobody truly cares. While this may be a stretch—certainly, the engineers, programmers, and builders care—the group is far smaller than a cadre of potential spectators than for human sports, which may have negative financial consequences for viewership, betting, and other sustainability metrics.

In removing the (literal and figurative) face of humans in sports, we encounter the challenge of robots not conveying emotion well, while humans are intrigued by the emotion athletes show (Kondratenko 2015). Humans are emotive and like to watch joy, excitement, sadness, and pain because it is relatable. Robo-sport will need to find a way to convey this information if it's to gain support.

It is also difficult to relate to robots. Robots are not role-models—they aren't admirable because they are incapable of being vulnerable, afraid, or taking a risk. They cannot be injured in a permanent way, nor can they die. Engineers will need to invent ways for robots to be imperfect, to be fallible and relatable, in order to make robo-sport as compelling as possible. Additionally, we often expect athletes to explain their choices, and developing AI that can explain its choices (Hagras 2018) is a way to make it more relatable. And even this may not be enough—imagine watching a Star Wars movie with *only* droids, and no human characters in it. We may watch it, and enjoy it, but it would be difficult to *connect* with. Sport, more than anything, is about the *human* spirit and *human* achievement. What is sport, without humanity? Without *empathy*?

These challenges are likely surmountable, but the solutions may not be available to us today. On the technical side, there are of course challenges related to sensing, perception, planning, locomotion, manipulation, and control, some of which we have identified and some of which are latent. With the pace of technological innovation, and with new tools in place to build clever, efficient, scalable, and cost-effective hardware, software, and electronics, these issues may not remain for long. However, it is difficult to speculate on how a problem yet to emerge might best be solved using technology not yet invented, and we therefore will not dig deeply into these "what-if's?".

As far as opportunities are concerned, it is clear to see that robotics and automation have and will continue to transform sports to increase and augment human performance and to create entirely new sports. Innovation in sports leads invention in robotics, and vice versa, with capabilities driving forwards and backwards between sports and non-sports applications of technologies, and the results are impressive. However, as sports and technology enthusiasts, we must be careful to build toward a sustainable future and to seek to humanize all that we do so as not to erode the purity of sports. Otherwise, we may end up in a future where human sport and robo-sport are divergent and break apart something that today brings us together.

Interestingly, robotics and automation itself might be viewed as a sport being played by researchers. We push boundaries to see what we can accomplish and strive to build the best mechanisms, computers, and algorithms simply because we can. Some tech-savvy spectators enjoy watching the evolution of robotics and automation, and these people can increasingly participate in robotic competitions—while others unknowingly benefit from robotics and automation innovations. The pace of play is relatively slow, the rules of engagement are informal, and noticeable step-changes are few and far between; but occasionally, major breakthroughs inspire the public to take notice and collectively celebrate invention, as was the case when SpaceX began to successfully land and re-use rockets (Wall 2015).

It is an exciting time to be involved in robotics and automation and the future is likely to be even wilder than is imaginable today. By developing robots and automation tools with sports in mind, and developing sports with robots and automation in mind, we will push the boundaries of what is possible and build a better, faster, stronger—and more exciting—future for players, spectators, and beyond.

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Robotics and AI: How Technology May Change the Way We Shape Our Bodies and What This Does to the Mind

Frank Kirchner

Abstract

In this chapter, Kirchner explores some of the exciting recent developments in robotics and artificial intelligence (AI) and the barriers to control complex mechanisms. He also offers a solution that he terms "the hybrid AI approach." Kirchner goes on to argue for using robots and learning as a way to achieve AI, an idea first touted by Alan Turing, and offers example cases of robots and AI in sports. Finally, he looks to the future and explores the possibilities and possible effects on the human body and mind of extensive physical interaction with intelligent machines.

1 Introduction

Robotics has undergone enormous application potentials and advances in the last ten years due largely to developments in other fields (Kim et al. 2017; Nag 2017; Nielsen 2017; Fin Ray Effect. 2013). For example, we have always looked for lightweight designs—particularly for mobile robots where weight is the main factor that limits the lifetime of the robotic system. However, options for lightweight design were limited; with 3D printing, it is now possible to create lightweight structures that serve multiple purposes like running wires or house batteries (see Fig. 1). Similar breakthroughs in the area of energy density in batteries and the resolution and size of sensors—cameras are the most prominent example—mean that we can now build robots light enough to carry their own weight with sensors

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Fig. 1 The humanoid robot, Charlie, in an upright position in the artificial crater environment of the DFKI Space Exploration Hall in Bremen. (*Photo* DFKI GmbH)

that can sample the environment to an extent previously unheard of, and these robots can run for extended periods of time on their own energy supply. But the biggest leap forward in the last decade came with chip technology, which drastically increased computational power. Through the extended life time of the robots and sampling the environment over longer periods of time, it became possible to witness longer term changes. Through enhanced sensor resolution, firsthand data on these environmental dynamics became available that we could not see before. But it is computational power that lets us use algorithms previously impossible to run online on a robot; we can actually make sense of the data and draw conclusions from that analysis to improve the performance of these robots in real-time.

Not unlike robotics, AI has also seen tremendous development; techniques like Deep Neural Networks (Nag 2017; Nielsen 2017; Fukushima 1980) can analyze millions of photos available on the internet to learn to distinguish cats from dogs or to boost natural speech recognition to an extent unmatched in the 50 years of speech processing before. With these advancements, we are in a position today to build robots that are kinematically complex enough so that they can be used in real-world environments without collapsing under their own weight or having to be maintained every ten minutes; at the same time, these robots run algorithms on their advanced processors that can take the enhanced sensor information they receive and analyze it in real time. From an AI-researchers perspective, we only need to learn how to actually make sense of it… Anyway, this is where we are in AI-enabled-robotics.

2 Issues with Control of Complex Mechanisms

Figures 2 and 3 are examples of complex robotic systems for operation in real-world environments. These robots employ complex kinematic structures that include parallel kinematics or closed kinematic chains as referred to in Fig. 1. To control such complex mechanisms (Widhiada et al. 2015; Nguyen-Tuong and Peters 2011), we quickly run into computational obstacles that are hard to overcome even with the powerful chip technology that we can use today. The problem is not in solving the appropriate equations needed to calculate joint positions and velocities to move the leg of one of these systems and acquire a solid stand in order to make the next step. The problem lies instead with the environments of real-world scenarios, which are extremely unfriendly[1]; each step then requires precise calculation, resulting in a massive calculation burden and massive communication bandwidth between the central calculating processing elements and the distal (joint) actuation elements. For very difficult environments, like rugged outdoor terrain, these new positions would need to be calculated and transmitted on a sub-millisecond scale.

Given the high degree of freedom that we need in such robots—and ignoring the power requirements of the processing elements—a walk through the forest is a sheer computational nightmare. With all the advances in chip, sensor, and battery technology, and even new materials and manufacturing approaches, it is still problematic to provide truly stable systems that can manage the complexities of their own bodies and (dynamic) natural environments. Thus, if we truly think about robots for sports activities, we need to reconsider the way we attempt to control these complex mechanisms today.

When discussing the control of complex mechanisms, it is important to clarify the kinds of systems that pose real challenges. Here, I outline two problematic systems:

1. Redundantly or over actuated systems: Systems that have higher number of actuators than needed e.g., snake-like robots (serial design) or parallel redundant actuation (Stoeffler et al. 2018).
2. Underactuated systems: Systems with fewer actuators than their total independent degrees of freedom (for e.g., humanoids, grasping problem, soft robots, etc.).

[1]From a control engineer's point of view.

Fig. 2 The robot system SherpaTT during autonomous execution of infrastructure assembly and sample collection using modular payload modules during field testing in a desert region in Utah, USA. (*Photo* DFKI GmbH)

Fig. 3 The kinematically complex robot, Asguard, moving in a lava tube on Lanzarote using methods for environmental detection, model-based motion planning, and reactive control. (*Photo* DFKI GmbH)

While some success in the control of complex series-parallel hybrid robots (Kumar et al. 2020) and learning approaches for control of soft robots has been demonstrated (Yu et al. 2019), hybrid AI (i.e. combining model-based control and learning approaches) is now being discussed as a promising approach (von Oehsen et al. 2020). I will now point out the advantages and shortcomings of these methods and provide my own support of hybrid AI.

Of course, there are already approaches to tackle the problem of controlling complex mechanisms. The most prominent and widely used approach is the so-called Whole-Body-Control (WBC) approach; it attempts to put some order and priority into the list of numerical equations to be solved in order to fulfill several (eventually conflicting) goals to carry out directed movements while maintaining stability in complex robotic mechanisms. Imagine a case where a robot like that shown in Fig. 1, needs to drill a hole in a wall using a conventional electric drill. The system has to deal with competing problems: First, the system needs to solve the control problem required to hold the drill in the correct position and with enough force. The second problem is the correct positioning of the arm that holds the drill—including gauging and modifying the distance to the wall as the drill moves while providing the appropriate amount of forward "pushing" force. The third problem is the conflict between pushing the drill against the wall, which then pushes the robot backward, and the overall goal of the system to stably stand during the whole operation. The WBC approach solves this multi-objective problem by prioritizing the multiple objectives and solving the necessary computations in this prioritized list to achieve the overall goal. However, if the list becomes too long and/or the mechanisms in question are very complex, which is often the case when dealing with closed kinematic chains or parallel kinematic chains, then this approach can reach its limits.

One much-debated strategy claims that it is possible to overcome these limitations by applying deep neural networks to this high dimensional control problem. With this approach, complex numerical solutions are not necessary; instead, it will suffice to supply the networks with enough data e.g., video sequences of moving systems in order to learn the control regime within the layered networks (Mohammad and Mattila 2018). While intriguing, it is unclear if the promise can, in fact, be kept and at what price.

It *is* possible to learn the control of a complex kinematic chain by analyzing huge amounts of examples of moving kinematic structures; and there are many examples available (Nguyen-Tuong and Peters 2011). However, no one so far has learned the control law for a complex humanoid robot (as an example, see Fig. 4) to be able to run through a forest. Of course, given the tremendous success that these methods have achieved in other areas like natural language processing (Fisher et al. 2016), it is too early to declare it impossible.

A more reliable approach, in my point of view, would be to combine model-based control theoretic approaches and deep neural network approaches; we call this a hybrid AI approach. A reasonable path would be to apply the "classical" model-based approaches to deliberate movements, especially those with no or low time constraints, and to apply Deep Learning approaches when the classical

Fig. 4 The humanoid robot RH-5 in an upright position. (*Photo* DFKI GmbH)

approaches reach their limits; for example, when passive degrees of freedom (Trivedi et al. 2008) connect with active ones, the area of modeling play in gears as well as compliant elements (springs and alike) that are interconnected with direct drive mechanisms. As demonstrated, it is difficult to control highly complex mechanisms in real-world environments over long time periods. A method that could adaptively cope with these dynamics, while still making use of the very powerful model-based approaches, would be a way to render real-world (life) applicability to robotic systems and allow for sports activities.

It should be noted that in sports activities, these robotic systems will be very close to or in direct contact with human beings. Hence, the classical position-driven control regime we use for stiff robots like in production settings cannot be used for safety reasons. Here, we have to go for compliant systems. Compliance can be realized by two strategies: Built-in compliance, where springs and spring-like mechanisms or materials provide compliance, which renders a control problem as the properties of these mechanisms and materials are difficult or impossible to model. And, compliance by control, where we use force control approaches instead of position control methods in order to compensate for external forces acting on the mechanism.

3 The Turing Option

Despite the problems outlined in the paragraph above, it is still useful and worthwhile to attempt creation of real-world (life) capable robotic systems because it will lead to understanding and creation of AI in technical systems. This idea was first suggested by Computer Science and Artificial Intelligence Pioneer Alan Turing in a famous paper written in the 1940s and only published in the late 1960s (Rolf 1995; Barry Cooper 2004). In the paper, Turing argues that, in order to achieve Artificial Intelligence, we should focus on building a complex robotic system capable of "roaming the English countryside" and employing an algorithmic control regime that will result in improved behavior with experience.

In a paper I wrote recently (Kirchner, F. (2020). AI-perspectives: The Turing option. Springer Nature.), I make the case that it is now time for AI and robotics to take up the strings that Alan Turing dropped in the last century when he presented the Turing Test; we call it the Turing Option. He realized that with the technology available it was impossible to actually implement his primary idea to use robots and learning as a way to achieve AI. At that time, the systems simply could not be realized: They would have been too heavy and bulky and collapsed under their own weight; their sensors would have been too low in resolution; and the processing power would not have been even close to what was required. Today, however, we *can* build such systems.

As a serious roboticist, it is probably not advisable to speak about robots in sports or robots in entertainment, etc., as for decades robots have been seen as a production tool. Serious attempts have been made (and succeeded) to control the stiff mechanisms, to the finest possible degree of precision, to mass-produce products for everyday use. The car industry, in particular, would not exist today if robots had not been used to bring down production costs. However, this focus on production has driven us away from seeing robots as a tool to do science. At the production site, there is no need to cope with dynamics in the environment or uncertainties; the systems have been built so heavy and stiff that movements would not be affected by uncertainties—their movements have been calculated precisely with the moments of moving masses and the forces required to accelerate or deaccelerate those masses.

This is not the kind of environment that we have to face in sports. To play sports, robots must be lightweight, flexible (compliant), and equipped with high-resolution sensors of various modalities. In industry, conversely, the environment is so static that sensors are not even used. For sports, the robots must also be mobile, autonomous, and even intelligent (for human interaction). In a nutshell, this environment or application is the exact opposite of what the production environment was (it does have to be mentioned that production has changed). Therefore, it is extremely interesting for robotics and AI researches to address areas like sports because it forces us to tackle the AI problem in a holistic way. For this use, we are required to create reliable and robust robotic systems that must develop some sort of intelligence.

4 Case Studies of Robots, AI and Sports

Introduced by Hiroaki Kitano in 1995, the most prominent case of sports and robotics is the RoboCup soccer event (Kitano et al. 1995); by 2050, their goal is to field a robot soccer team capable of playing and defeating the human world champion soccer team. Kitano understood the idea behind the Turing option very well—though he does not mention it by name—when he conceived of the challenge to create a robot robust enough to physically survive a full 90 min, not to mention the vast amount of AI algorithms (see (Thrun and Burgard 2005) for a survey and (Fisher et al. 2016) as an example for communication) to solve all problems presented by a soccer game. To simply control the complex physical structure with robustness, precision, and reliability in the face of a highly dynamic environment is the first challenge. The second challenge is the perceptual problems—identifying the ball, distinguishing opponents from teammates, and planning of game strategies. Kitano tasked himself and the larger robotic community with an AI-complete challenge that requires overcoming a huge mechatronics threshold before beginning to tackle the AI component. (I am a proud member of the University of Bremen and the DFKI, which hosts the best robot soccer team to date, B-Human.)

Because we are close to solving the mechatronics threshold, we are in a good position to think about the combination of sports and AI-enabled-robotics in many other areas. One interesting area is training or teaching. AI-based-robots could train athletes—personalizing guidance to an extent that could hardly be matched by any human trainer. Using so-called exoskeletons (see Figs. 5 and 6) that provide a high degree of active degrees of freedom that can be force controlled in an extremely precise and sensible way, it is possible to teach movements to human athletes. In this process, the exoskeleton would register the movements of the human and register any divergence from the optimal trajectory; it would smoothly and sensibly correct human movements until the optimal behavior is reached. In order to correct the movement of the human, the exoskeleton would use the force control approach—slightly increasing resistance to the human movement, thereby correcting it steadily over time. Time is an important factor in this way of training; the system could reference “memories” of past training sessions and analyze the advancements, or speed and rate of training success, and adopt the corrective measure accordingly. Needless to say, this personal trainer will never fatigue, have a bad

Fig. 5 The upper body exoskeleton. (*Photo* DFKI GmbH)

day, or be bored by the slow learning rate of its student. The athlete will always have the full and personalized attention of the system. The system could also be used to train at any time.

Exoskeleton training systems are already under development for use in rehabilitation. Figures 5, 6, 7, 8 depict exoskeletons created to assist in rehabilitation after strokes and are intended to be used in combination with a human therapist (Kim et al. 2017). For example, the human therapist will grab the arm (inside the exoskeleton) of the human patient and perform a movement intended to stimulate the patient's neuro-muscular system for rehabilitation purposes. This movement, induced by the human therapist, is recorded by an exoskeleton and can be repeated to provide the continuous stimulation of the neuro-muscular system without the direct intervention of the therapist. At the beginning of the rehabilitation process, there is little to no active movement by the patient; over time, with the increasing success of the therapy, the muscular activity of the patient slowly comes back. Because of the force control approach, the exoskeleton perceives increasing muscle activity of the patient and slowly reduces the active support of the patient's

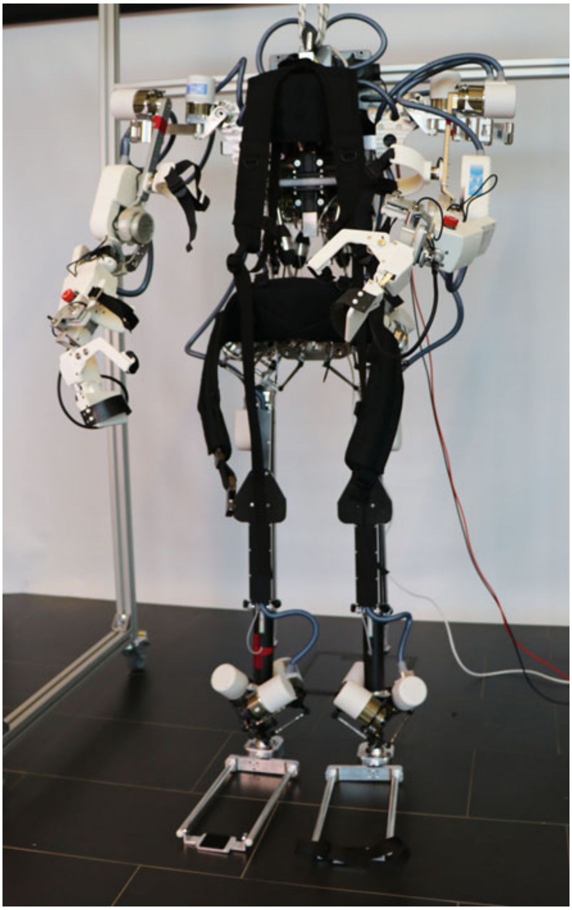

Fig. 6 The full-body exoskeleton for walking support. (*Photo* DFKI GmbH)

movement; the steady removal of support maintains the challenge on the neuro-muscular system of the patient and increases rehabilitation success.

Because the human patient can do this training without the help of the therapist, the exoskeleton provides a positive mental stimulus to the patient. It is well documented that the positive mental state of a patient is an important basis for successful rehabilitation. In order to increase positive feedback, the patient must actively initiate the movement. Using modern AI-machine learning techniques, it is possible to analyze physiological parameters like EEG and EMG (Fig. 9) and predict when a patient wants to initiate a movement. In other words, when a patient thinks about moving his arm, we are able to recognize this intention—actually before the patient himself becomes aware of it—and time the initiation of the movement in a way that the patient has the impression that his intention led to a movement of his arm. Even though the Exoskeleton carried out the movement, it is this belief of the patient that creates the positive mental state. Of course, the positive

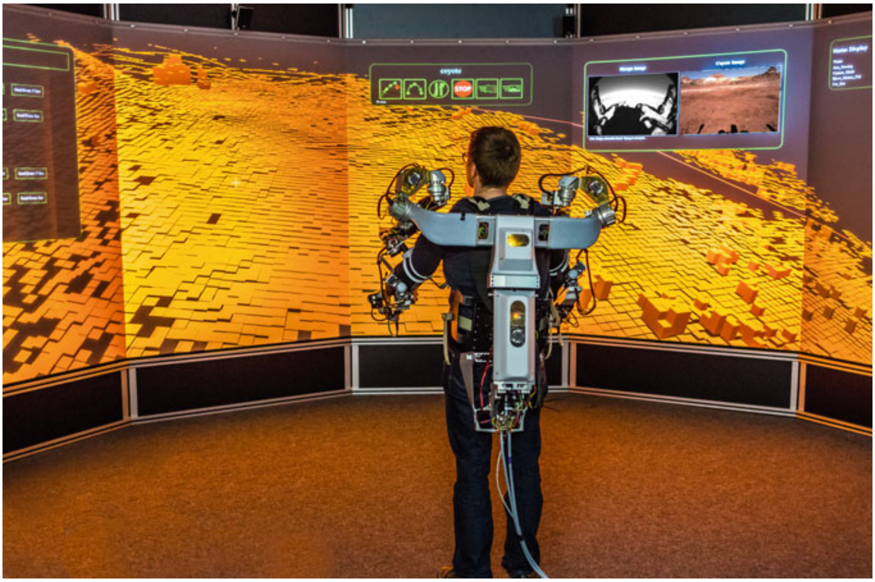

Fig. 7 The upper body skeleton in the cave. (*Photo* DFKI GmbH)

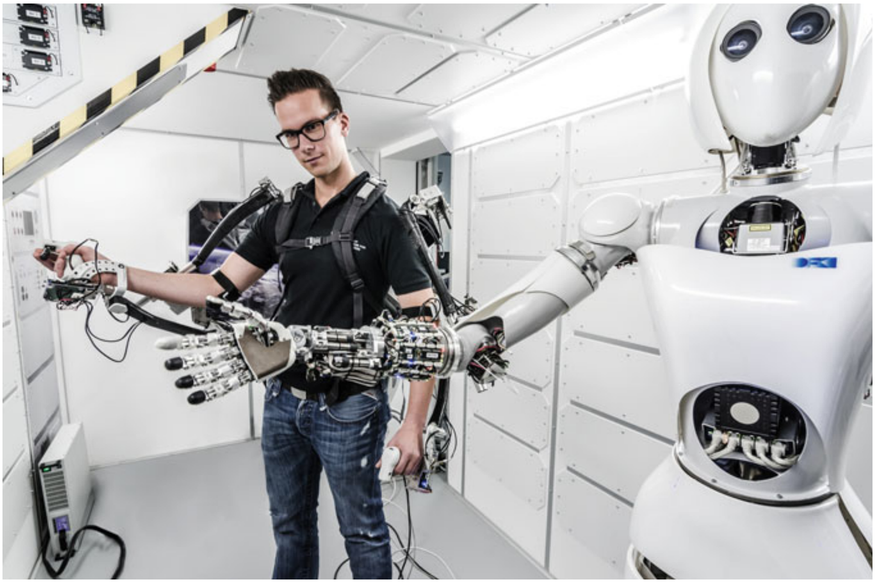

Fig. 8 The passive upper body exoskeleton and the humanoid robot, AILA. (*Photo* DFKI GmbH)

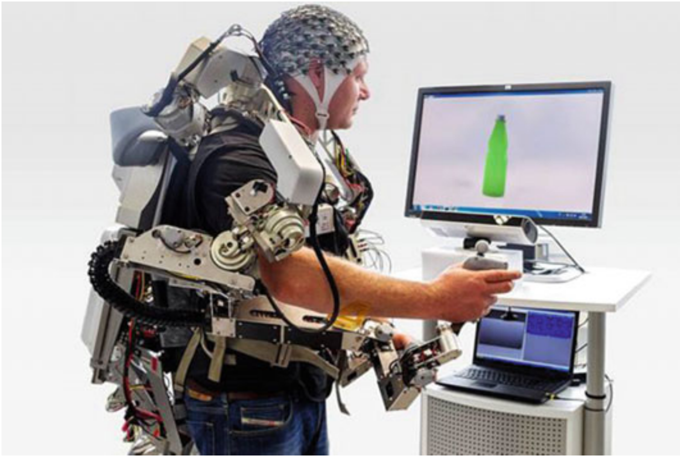

Fig. 9 The upper body Exoskeleton and online EEG Analysis for intention recognition. (*Photo* DFKI GmbH)

mental state is as much a guarantee for successful training in sports activities; the combination of user intention recognition and mental state with the Exoskeleton driven muscular activation is a perfect basis for athlete training. Instead of relying on a human trainer to correctly gauge the athlete's mental state, motivation level, stress level, etc., to design training sessions, we can now use the personal profiles generated from the analysis tools described above to precisely tailor training sessions. In fact, this technology is already under discussion to provide training for ISS astronauts in preparation for longer space travel like missions to Mars.

In my point of view, Kitano's vision of a robotic soccer team beating a human team will be realized sooner than 2050, perhaps even in the late 2030s. Besides soccer, we will also see football, baseball and even martial arts as new avenues of competition for humans and robots. Martial arts provide an ultimate challenge to AI-Enabled-Robotics research because control over a very complex body must be mastered to perfection. Therefore, this is a field that will be tackled by scientists sometime in the 2030s and may even become a benchmark for performance of robotic systems controlled by AI-methods.

In the above scenarios, we have intelligent, lightweight, non-harmful, learning-capable, fully human-centric technical devices that we can effectively control despite their high kinematic complexity. Of course, this is a vision yet unrealized. That said, let us assume for a moment we have these AI-enabled-robotics and we could use them for sports and other physical activities. What would be the result?

It is not a new idea that the body shapes the mind (Gallagher 2005) Gallagher discusses several effects both bottom up and top down on this duality. However, if we consider the fact that body and mind have evolved in a coevolutionary process, it is clear that many parts and functions of our central nervous system have formed specifically to handle an increasingly complex physical structure (the body). As a result, the central nervous system and anatomical structures became more complex as connectedness of these structures formed to deal with this growing complexity. It is important to distinguish between "to deal with" and "to control" because the nervous system is not able to guarantee perfect control of the body under all circumstances (as we would want as engineers when we speak about controlling a technical system); the most obvious cases are that we sometimes fall, things slip from our fingers, or we use the wrong grip for a fork at dinner. In the first two cases, the control structures in our nervous system, in combination with the activation cycle of our muscles, are simply too slow to counteract the effect of stepping into a hole in the ground or a sudden change of the center of mass if we are holding a bag of rice. In the third case, there is an error in the deliberate motor planning structures of the central nervous system, which we can correct as soon as we realize that it is a bit awkward to eat peas with the fork if you hold it like a hammer.

From the engineer's point of view, the control structures of the body are not perfect; the body can manage the complex kinematic structures so that roughly 95% of cases are in "control." Why did mother nature stop at 95%? Why not achieve 100% so that events like stumbling or slipping do not happen? This is likely because we are not machines optimized to serve a single purpose and we (evolution) found a good balance between handling the body while hunting prey (thereby being able to survive) and controlling the structures to play the violin (thereby having a reason to survive). It also tells us is that the interplay between body and mind (control structures) is fine-tuned to adapt to changes. Further, the motoric elements—the muscles, bones, and tendons—are adaptive as well. For example, astronauts that spent time in zero gravity will have bone structure degeneration and decreased muscle mass.

If and when we train this fine-tuned system with robotic devices, we do so without full understanding. In fact, we are speculating based on observations in similar cases. If we return to the astronaut example, we can actually observe that they have no difficulties controlling the body structure. As soon as they return to earth, however, they can hardly walk; this is not a problem of control but of the degenerative effects of space flight to the skeleton-muscular system. It may be safe to say that the control part is not affected. When we have colonies on the moon or Mars and people spend a good part of their lives under reduced gravitational conditions, it is reasonably safe to assume that both the muscular-skeleton systems as well as the nervous system would change. People would likely have finer body structure and grow taller; reduced mass would allow them to grow longer extremities while still being able to handle a payload. But would these people also think in a different way? Maybe. If something unthinkable on Earth, like casually jumping over a one-meter fence, is normal on Mars, it will shape the way we perceive, represent, and categorize the world.

Thankfully, we do not have to wait until we have colonies on the moon to discover the result of enhanced physical possibilities. There are serious studies that show that playing computer games boosts fine motor skills (Borecki et al. 2013).

And, we know from neurophysiological studies that watching a person performing a task shapes the function of neuroanatomic structures that are concerned with movement control. This effect goes back to so-called mirror neurons (Rizzolatti and Craighero 2004) that lead to a co-activation of neural areas for motor planning and execution control if neural areas of perception of movements are active.

This is a two-way street, however, as performing actions also influences a whole network of perception. Imagine using a screwdriver to drive a screw into a piece of wood. As you turn the tool and feel the resistance you expect to see the screw turning (even if you do not look); the perception is the result of the activation of memory and models of the process based on previous experience. This is how today's industrial robots work. The screw must turn because this is what their model predicts. But how does assisted or guided motor skill learning shape the formation of these models? With assisted motor skill learning, as described in the rehab scenario, we lose the ability to actively explore the possibilities of our physical bodies; we constantly perform a specific type of learning called procedural learning and miss a very critical part of learning called active explorative learning.

We all experienced active exploration learning when we learned to ride a bicycle. In the first few trials, maybe we fell off the bike or had to hard stop by using our feet. Perhaps training wheels helped us to overcome the difficult starting and stopping phase. But these training wheels were mounted in such a way as to not touch the ground during forward movement. The guidance given by these wheels was just enough to get the bike rolling, but not enough to keep it stable no matter what we did on the bike. Here is where the active exploration part comes in—it drives the system into the boundary areas of controllability in order to understand and actively learn where the boundaries are. This is a case of managing a problem instead of controlling it completely. Our central nervous system, through active exploration learning, learned to stay away from these boundary conditions because, once there, control is lost. This management, or avoidance of the uncontrollable situations, leaves us with the part of the problem handleable by model-based control. It is necessary, therefore, to make mistakes and go beyond the perfect movement prescribed by the trainer; without them, you lose the body experience that leads you into the boundary areas of controllability, which is mandatory for our nervous system to come up with strategies to handle problems.

5 Conclusions

In summary, the prospects of robotics in sports are manifold. With increasing improvement of hardware, we will eventually observe human–robot competitions in physical games, as we can already see it in Chess, Go, and other games that do not require complex robotic hardware. However, I have tried to outline the obstacles that need to be overcome before these kinds of competitions make sense. I still have a running bet with my students that they will not be able to build and program a robot that can beat me in karate before I retire (this was some ten years ago and I still have a good ten years to go until official retirement). I proposed this bet to motivate students to tackle the AI-complete problem in a holistic way and to turn away from the standard robot applications in isolated domains for well-defined problems and friendly environments. So far, I am confident that I will reach retirement without being beaten up by a robot.

The story is different for other applications like using robots as trainers. Within the next couple of years, we will see robots as trainers in the form of intelligent orthoses and partial exoskeletons; they will be used to train specific body parts for home-based exercise—maybe to recover after an injury or an operation. Likely, robot trainers will be employed first by top athletes in the high-end, money-driven sports like soccer, football, and baseball. Eventually, their use could spread into what we call “Breitensport” in Germany, which refers to the infrastructure and support for small sports clubs that provide facilities and (human) trainers for laypeople. The spread into Breitensport would sooner happen in countries like Germany, as these countries provide public funding for activities on a community level and the sports club culture is very active and highly recognized.

For more commercially driven applications, however, one could very well imagine that gym equipment could transform from iron-pumping stations into more intelligent robotic devices that can simulate the weight by force-controlled motors, provide personalized training programs, and adapt to the progress of the user on an individual basis. If these devices spread quickly, it would also be easy to imagine that a device used on overseas holiday could connect to home- or gym-based equipment and download the training program and personal profile via the cloud.

What are the implications? We can observe that ongoing, personalized interaction with regular computer games does influence various aspects of internal model formation and, consequently, pathways and connectedness of neural structures to represent the world and interaction with the world. This is not to say that this influence is negative as we do see some evidence (Rizzolatti and Craighero 2004) of increased reactivity, motor learning, and planning capabilities from the interaction with classical computer games. However, the interaction of human and computer is mostly visual and the motoric part restricted to activities of the arms and hands.

In more advanced interaction scenarios with technologies like virtual reality headsets in combination with treadmills, we can observe that the interaction quickly overstresses the user. Most likely, this is due to insufficient performance of the technology as walking on a treadmill while watching a virtual world in a headset does not yet feel very real. You feel the headset on your face and the treadmill does not give the same level of haptic feedback to your feet like walking in the real world; so, the brain is confused as the visual stimulus is next-to-perfect while the rest does not feel quite right. I assume this is because we are basically model-based control machines that have learned to cope with an underactuated system. Underactuated technical systems, as described above, cannot be controlled in an optimal way as they are lacking degrees of actively controllable degrees of freedom for which a control law could be formulated. Instead, they come with “uncontrollable” dynamics for which our brained has evolved to apply learning techniques.

Therefore, our brain has no strategy to deal with a visual stimulus that triggers previously learned control policies to the haptic sensor information, which is then not matched by the actual haptic feedback. In other words, if you see—via virtual reality goggles—that you are walking on a sandy beach, the brain predicts specific haptic feedback from the interaction of your feet with the sand. The brain would then prepare to activate control policies to cope with disturbances expected from this kind of environment. If the haptic feedback is not the one predicted and rather more like walking on a sidewalk, there is a mismatch for the brain; the end result is discomfort and misbehavior. There is no switch to tell you to ignore strange haptic feedback; these control mechanisms have evolved over hundreds of millennia and the appropriate control parts of the brain are, therefore, hardwired into our system. As soon as you stop to actively tell yourself to ignore the strange haptic feedback, the brain would flip back to standard procedure.

If we had the technology to perfectly match the haptic feedback, my guess is that it will lead to a next evolutionary step in human development. We would then enter the age of the homo-digitalis—an era in which the human brain is challenged to cope with a virtual world that requires new principles and laws. I have no doubt that the brain will manage this adaptation and that evolution will be a clever enough designer to provide solutions. Similarly, the brain would have to adapt if humans were to establish permanent colonies on other planets with different parameters. If we assume that the closest habitable planet is a few hundred light-years away, an application to train the brain to the adaptation process and start the evolution of the brain would be most useful.

In the meantime, we will continue to develop these technologies and, hopefully, assist people in their everyday lives. Beyond applications in rehabilitation social activities like sports are on the way. Robots will be sparring partners, trainers, and teachers; and eventually, we will also have robots in competition with other robots. The RoboCup dream of Kitano (Kitano et al. 1995) will be realized and then, of course, we will have a robot soccer league in which robot teams compete while humans watch.

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The Reach of Sports Technologies

Martin U. Schlegel and Craig Hill

Abstract

Schlegel and Hill outline the megatrends of sport in Australia and introduce an additional megatrend, the use of sports technologies, which they explore in more depth. They then argue that sports technologies—wearables, internet of things (IoT) applications, media, and communications—can provide the basis for validation, technology transfer, and diffusion of knowledge into fitness, wellness and health, as well as occupational health, safety, and defense. They explain how sports technologies impact multiple verticals including insurances, stadium infrastructure and maintenance, and sport broadcasting. Finally, they explore the challenges presented by the use of sports technologies including the barriers to open standards, security, and privacy.

1 Introduction: The Present State of Sport

When the Futures Research Team at the Commonwealth Scientific and Industry Research Organisation (CSIRO) and the Australian Sports Commission (ASC) teamed up to identify the megatrends shaping sport over the last decade, they uncovered a dilemma. Whilst Australians love sport, which has always been part of the cultural identity, the country continues to face challenges in terms of modern lifestyle risk factors and certain long-term health conditions. At the time, Australian statistics (Commonwealth of Australia, Australian Government—Productivity

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Commission 2017) confirmed that 5% of people have to live with diabetes and another 5% of people suffer from a heart attack or stroke. In terms of identified lifestyle risk factors, almost 17% of people have been diagnosed with high blood pressure, 20% of people are considered obese, and nearly half of Australia's population participates in limited or no exercise. As a result, governments, not only in Australia, but around the globe, have seen sport as a means of disease prevention.

Beyond declining participation, the CSIRO and ASC identified the following megatrends that continue to change sport (Hajkowicz et al. 2013): Firstly, the study identified that individualized sport and fitness activities are on the rise. More and more, people are having to "fit sport into their busy and time-fragmented lifestyles to achieve personal health objectives". Sport has to be, according to the first megatrend, "a perfect fit," to coincide with other demands. Secondly, participation rates in aerobics, running, and walking, along with gym memberships, have all risen sharply over the past decade; meanwhile, participation rates for many organized sports have held constant or declined. "People are increasingly opting to go for a run with their headphones and smart device when the opportunity arises rather than commit to a regular, organized sporting event".

Lifestyle, adventure, and extreme sports are particularly popular with younger generations as reflected in the second megatrend, "from extreme to mainstream." "Lifestyle sports typically involve complex, advanced skills and have some element of danger thereby satisfying some form of thrill-seeking. These sports are also characterized by a strong lifestyle element and participants often obtain cultural self-identity and self-expression through participation". It has been noted, that lifestyle and extreme sports are attracting more participants through "generational change and greater awareness via online content".

The third trend, identified as "more than sport," is based on the fact that governments, companies, and communities increasingly recognize the benefits of sport beyond competition. "Sport can help achieve mental and physical health benefits, prevent crime, and promote social development and international cooperation objectives". The Federal Government of Australia even defines sport as a diplomatic asset due to its economic importance, power to unite, and universal adoption (Commonwealth of Australia, Australian Government—Department of Foreign Affairs and Trade 2019).

Australia, similar to other countries of the Organization for Economic Cooperation and Development (OECD), faces an aging population. This shift, identified as the fourth megatrend, "everybody's game," outlines the change in the types of sports people are partcipating in and how people take part in them, e.g small-sided or shorter games. Participation data indicates that Australians are embracing sport into their old age. Accordingly, sports of the future will need to cater to senior citizens in order to retain strong participation rates amongst older demographics.

Sports will also need to cater to the changed cultural make-up of Australia. "Australian society has become, and will continue to be, highly multicultural. Population and income growth throughout Asia will create tougher competition and new opportunities both on the sports field and in the sports business environment. The fifth megatrend, "new talent—new wealth," is based on the fact that the way of living in Asian countries is changing and governments" invest heavily into sports capabilities.

Furthermore, the report identifies that "market forces are likely to exert greater pressure on sport in the future". As a result, loosely organized community sports associations will be replaced by organizations with corporate structures and more formal governance systems". The report identified this transition and changes in business models as the sixth megatrend, "from tracksuits to business suits."

Whilst all of the megatrends identified are still relevant and are expected to continue shaping sporting trends into the next decade, the consultancy report only touched on the changes and opportunities that sports technology plays in shaping the megatrends and driving some of the societal responses. As such, we argue that the proliferation of technology into all aspects of sports could be identified as a separate megatrend, in addition to the six trends previously identified (see Fig. 1).

2 The Quantified Self as a Starting Point of the IoT Sport Future

Charting technology trends in sport to identify probable, plausible, and possible scenarios can assist in exploring the future (Voros 2003). As such, the notion of the *quantified self* (https://quantifiedself.com), whereby an individual makes relevant discoveries using their own, personal, self-collected data, overlaps in significant ways with the megatrends identified in sport at the end of the last decade. More and more, people engage during individual sporting activity through their personal devices and utilize sensory data to monitor their activities, training progress, or performance improvements. Such activity data combined with sensor data from equipment or surroundings, when connected to core computing memory and tracked over time using cloud-based infrastructure, forms the internet of things (IoT) as a network of people, objects and services converging the physical and virtual world (Kagermann et al. 2013) (see Fig. 2).

People use the information for motivation and self-improvement. In addition to the trend in which the individual collects data and connects to the cloud in order to analyze details and trends, there is also a social component. According to a fitness survey (Burr 2017), an estimated 70% of active people use an app to track a fitness program with two-thirds preferring to workout in groups including virtual competition.

Increasingly, technology will replace the human expert in terms of coaching or motivational activity. In the future, virtual coaching could also extend to new business models, where celebrity athletes and coaches use machine learning and artificial intelligence to personalize and optimize training regimes for consumers who subscribe to their services. Combined with automated synthetic media technologies, for example, personalized instructional videos that are created using

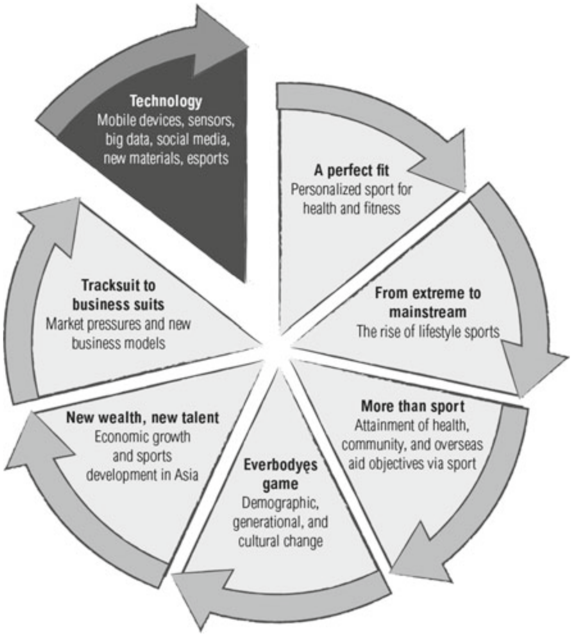

Fig. 1 Megatrends and key drivers in the future of sport (adopted and amended from (Hajkowicz et. al. 2013)

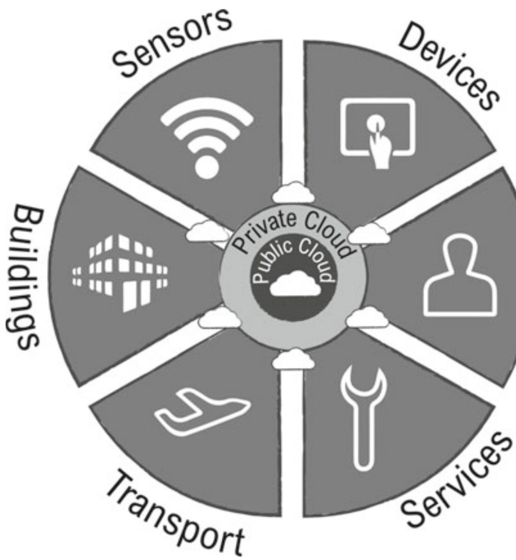

Fig. 2 The internet of things: Networking people, objects and services

artificial neural networks (so-called “deepfakes”), could be marketed by sports organizations, apparel providers or celebrity athletes, and coaches to deliver personalized and motivational instructions to consumers (see Fig. 3).

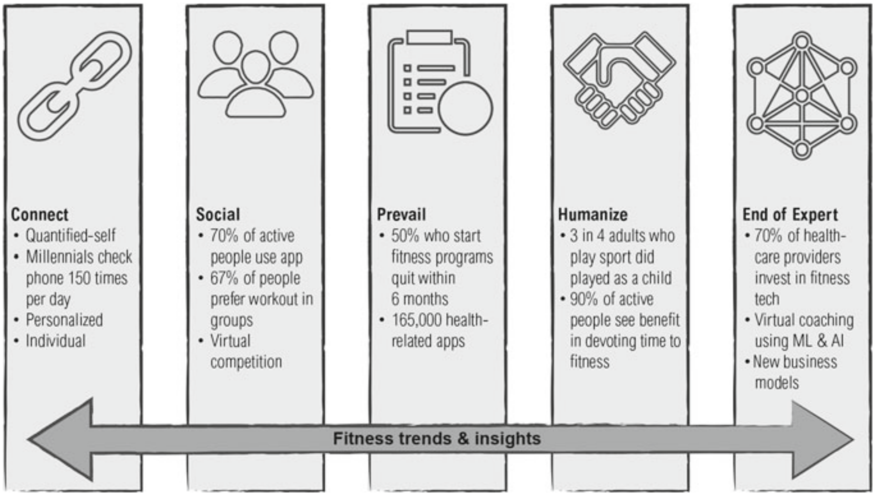

Fig. 3 Insights from fitness survey and resulting trends

Going forward, it is widely anticipated that aggregated data can assist in tracking trends, risk profiling, and, ultimately, disease prevention. Accordingly, sports apparel companies, device and IT providers, fitness and wellness companies, insurance and healthcare providers, as well as governments and regulators are exploring the various aspects of fitness, wellness, and digital health.

Depending on jurisdiction, political system, and accepted social norms, data management in a networked-IoT cloud structure could be administrated by governments, corporations, or future peer-to-peer-like cloud structures. In a world where users become increasingly cognizant of privacy and security concerns of individual data storage and data aggregation by governments and corporations, a peer-to-peer-like cloud structure could form a data ecosystem to manage data storage and aggregation (see Fig. 2). For example, individuals could store their personal data in a private micro-cloud and only share a selected range of data points through a public cloud. Data aggregation, statistics, and analysis would only be enabled for those data packets knowingly and intentionally shared through the public cloud.

Looking further into the future, such a private–public-cloud infrastructure could also stimulate new business models. If governments maintain such data ecosystems, for example, tax-incentives could drive data-sharing and data-aggregation on a consumer-to-government and business-to-government level. Conversely, in a jurisdiction where corporate entities maintain such data-ecosystems, a "pay-with-your-data" model could potentially replace the freemium business model. Such changes in business models in the context of use of private data by corporations have already been canvased by law and business academics around the globe (Posner 2018; Mitchell 2018).

In either scenario—a pay-with-your-data business model or government-driven incentive scheme—validation, accreditation, and administration of devices and sensors will result in a regulatory challenge. Already, governments and regulators around the globe are closely observing the space where fitness devices crossover into the domain of medical devices (Albrecht 2016). In certain cases, this has been triggered due to claims made by suppliers of fitness trackers in advertising as well as questions about potential regulatory approval or accreditation processes. A second regulatory focus is on identifiable health information, which is aggregated, stored, or transmitted. In certain circumstances, such information even today is considered to be protected health information, based on legislation in the respective jurisdiction (https://www.fda.gov/medical-devices/digital-health). Thirdly, as the regulatory environment for wearable devices continues to evolve, different types of testing will be required to evaluate their safety and reliability. Suggestions range from testing electrical and mechanical safety, identifying chemicals or any hazardous materials, electromagnetic compatibility (EMC) and performance, functionality and data integrity, and security (Solmaz-Kaiser 2017). Such testing and certification under a private–public data-cloud model would need to extend to quality, integrity, and security testing of data exchange and could require development of further standards for application programming interface (API) protocols including potential data gaps with possible biases arising.

However, it is important to highlight, that the collection of data can only serve to illustrate facts. Significant knowledge is only derived by analyzing the data, distilling useful insights, and using such details to initiate meaningful action. Such insights and knowledge, regardless of whether the process is driven by a high-performance manager in elite sports or an ambitious weekend warrior, will, in the future, support and enable new business models. For example, this could be achieved by pay-with-your-data or offering dashboard and trend analysis as a service or subscription to the athlete.

Individual activity data can be aggregated to provide insight into usage of urban landscapes, as demonstrated by the Running Amsterdam initiative. Using "crowd-sourced" data, the project maps running, cycling, hiking, skating, and other activities to reveal active bottlenecks across various precincts in the city. The knowledge gained from the analysis is being translated into strategies and design proposals for smart cities and landscapes (https://www.track-landscapes.com/track). Beyond crowd-sourcing data for purposes of planning, another possible application of a real-time connection between athletes using smart devices and physical infrastructure could mean street lights along jogging trails automatically turn on and off or switch from a night-modus to a flood-light modus as the athlete progresses on his or her dawn or dusk training activity. Similar to the green laser light beam, which guided Eliud Kipchoge to his sub-2-hour marathon in Vienna in 2019, recreational athletes using IoT-connected wearables could use smart-city lighting infrastructure alongside their running or cycling trails to pace their training. IoT-connected infrastructure paired with wearable devices could be operated for simple timing and registration purposes of participants in a community event. Furthermore, access to sports facilities and necessary equipment could be administered through IoT-enabled infrastructure thereby eliminating the need to staff locations to maintain opening hours. Such IoT-enabled infrastructure, for example, could operate similarly to the e-scooter business model using IoT and geo-fencing technologies.

3 The Convergence of Sensors and Markerless Video

Following the megatrend of more personalized engagement with sport and the tendency to track training regimes, activity loading, and performance improvement, more and more recreational athletes use non-invasive individual monitoring devices. Contrary to professional sports where monitoring of biological and medical parameters through invasive sampling methodologies in combination with global positioning systems (GPS), radio-frequency identification (RFID), and video-based devices is utilized, the consumer market for the recreational or ambitious sports enthusiast has grown due to the proliferation of commercially available, wearable, sensor technology. Vital signs such as heart rate, temperature, respiratory rate, and sweat rate are combined with measurements of movements. In practice, this can range from sensors and devices close to the body to more specialized devices on or in the body (see Fig. 4). In particular, the rapid increase in the number of apps utilizing sensor technology embedded into smartphones has been complimented or replaced by wrist-worn activity trackers or smart watches measuring close-to-the-body parameters. With the exception of helmet cameras, other head-worn devices, such as in-ear headsets or multi-motion sensor devices worn between the shoulder blades, have gradually increased in uptake by the general public. On the other hand, sensors embedded in sports apparel and footwear have been characterized by problems with performance, slower-than-expected adoption, or even failure to deliver financial returns in the time anticipated (Gartner 2018).

Studies have shown that in some cases scientific evaluation of the reliability, sensitivity, and validity of data derived from wearable sensor technologies is limited (Düking et al. 2018). A comprehensive overview of wrist-based devices that tabled the type of training parameters monitored, the type of health parameters recorded, and the sensor technology used (Düking et al. 2016) found that it is necessary to employ a combination of wearable devices in order to obtain an overall picture of an athlete's training progress and health status. At the same time, the studies confirm what athletes, coaches, and practitioners have insisted on: the importance of minimizing the time required to kit out an athlete with the wearable equipment and avoiding, as much as possible, impeding or disturbing the athlete's natural way of exercising. Integrating sensors and devices into sports apparel ("smart sportswear") has been somewhat behind expectation due to existing limitations on data transfer, battery power, and energy harvesting. Athletes demand that smart sportswear be flexible and comfortable enough to wear without causing discomfort or restricting performance and skill execution.

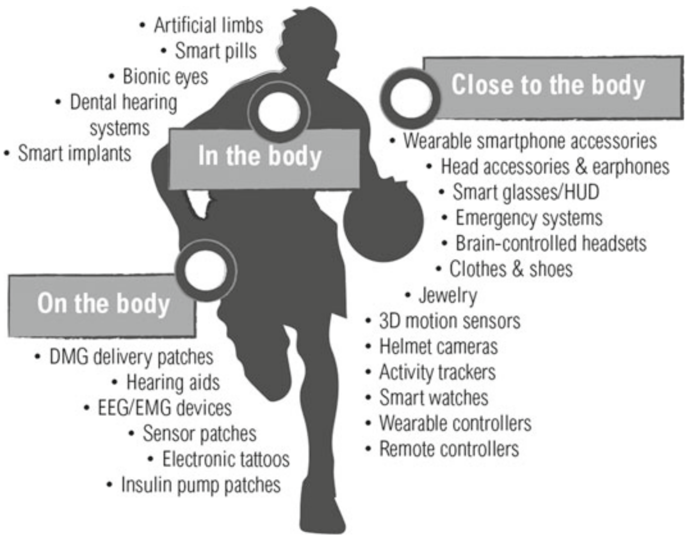

Fig. 4 Location of athlete sensors and devices (adopted from Stammel 2015)

Particularly in professional sports, coaches and physiotherapists have a long history of reliance on visual motion capture in both laboratory and game applications. In the early days of motion parameters and positioning based on global navigation satellite systems (GNSS) and local positioning systems (LPS), a disparate and disconnected interpretation of athlete performance based on video versus sensor-based movement analysis was noticed. However, full data integration and alignment between video and sensor-based data now promises to produce a more complete understanding of performance analysis, whereby sensor-based data enhance the video frame like closed-captioning can complement a television broadcast.

In the past, biomechanical analysis in sports or clinical science relied on placing markers on subjects to capture a range of motion using high-speed video camera technology (https://www.vicon.com). Currently in the lab, the integration of data from inertial and infrared-depth sensors fused with video images is on the brink of delivering full capture of position, acceleration, and orientation with the ability to calculate balances, range of motion, and alignment (https://www.valdperformance.com/humantrak-movement-analysis-system/). Similar to this in-lab assessment, providers of electronic positioning and tracking systems (EPTS) (https://football-technology.fifa.com/en/media-tiles/fifa-quality-programme-for-epts/) are starting to integrate data from positioning systems with video analysis (www.catapultsports.com). Furthermore, the reference and alignment of a sensor-based system with a globally recognized standard for motion capture is used as a gold standard to quantify the accuracy of data collection, processing, and analysis (https://football-technology.fifa.com/en/media-tiles/test-method-for-epts-performance-standard/).

In the future, fusing sensor-based data with video information will enable three-dimensional capture of biomechanical movements using markerless motion capture. Combined with integrated sensor systems, such developments can ultimately produce multi-scale human performance modeling and simulation in order to understand complex biomechanical and physiological components of physical performance. For example, muscle activity and fatigue performance parameters using a smart compression garment have been compared to electromyography (EMG) during high-speed cycling (Belbasis and Fuss 2018). The study validated that muscle activity and fatigue can be obtained from a smart compression garment using pressure-sensing technology. Markerless assessment of biomechanics versus power output has also been tested in on-road bicycle riders (Saylor and Nicolella 2019) in an attempt to improve athlete efficiency and performance. Both examples highlight that a fully comprehensive understanding of the individual biomechanics, efficiency of skill execution, and necessary training requirements, given an athlete's aptitude, will require the convergence of non-invasive, sensor-based data, video-based footage with blood-marker diagnostics, and possibly genetic information. The end result of such a convergence will be a complete customization and personalization of an athlete's model. Such comprehensive models will enable digital simulations with the ability to scenario-test training regimes or return-from-injury plans on a digital replica of a particular athlete (digital twin), for example.

With respect to self-optimizing algorithms, it is noteworthy that understanding human movement is a prerequisite for computer visioning, machine learning, and artificial intelligence (AI) to fully interpret human performance. Ultimately, such advancement will change the existing notion of human performance analytics from "sense and respond" to "predict and act." In the future, machine learning and artificial intelligence algorithms that are based on fully converged information derived from biomarkers, non-invasive sensors, and devices combined with video analysis are expected to alert coaches and athletes of risk of injury prior to occurrence, rather than detecting such an event and suggesting a corrective action. In addition, AI may ultimately be able to anticipate in-game play; for example, anticipating movement of players and teams and creating playbook scenarios. Once validated in elite sports, transfer of the technologies into fitness, wellness, and health could also provide healthcare and insurance providers with an opportunity to expand or revise their business models going forward.

4 Effect of the IoT on Industry Verticals

4.1 The Insurance Conundrum

Since its inception, the business model of insurances has been characterized by "risk transfer" and "loss-spreading" arrangements. Individuals and organizations purchase insurance products through payment of a premium and the risk is transferred to the insurer. Typically, insurers themselves spread parts of the risk to another insurer (so-called reinsurance). In Australia, like many other countries, a legislative and regulatory framework governs general administration of insurances (Commonwealth of Australia. Australian Prudential Regulation Authority Act 1998), corporate integrity, consumer protection and licensing (Commonwealth of Australia. Australian Securities and Investments Commission Act 2001), as well as anti-discrimination regimes (Commonwealth of Australia. Age Discrimination Act 2004). Under such a regime, the insurance industry is provided with a number of exemptions for which insurers may discriminate. One of these specific conditions, on which it is reasonable to discriminate, is based on the availability of "actuarial and statistical data". However, as pointed out by the Australian Law Reform Commission, "much of the data relied upon by insurance companies in the underwriting and pricing process is not publicly available"" (https://www.alrc.gov.au/publication/grey-areas-age-barriers-to-work-in-commonwealth-laws-dp-78/4-insurance/insurance-in-australia/).

For some time, health insurers have tried to encourage policyholders to adopt healthier lifestyles by providing nutritional, exercise, and general lifestyle advice through media publications and member newsletters. Despite this, there is only moderate uptake and use of insurance-provided fitness trackers and smartphone apps by Australian policyholders. Some consumer advocates have voiced the concern that customers subscribing to an insurance-funded fitness tracker or smartphone app program will only provide the statistical data to the insurer, which then might be used to discriminate and potentially result in higher premiums for some consumers. As such, the uptake of third-party smartphone apps and tracking devices provided by sports apparel companies or third-party technology providers have seen by far a higher rate of adoption compared to insurance-funded schemes. However, a translation of knowledge from sport and fitness into wellness and health could present a challenge to the current business model of healthcare and insurance providers. Armed with a plethora of individualized activity data, biomarker data from non-invasive sensors and devices, recorded health data, and purchase history of over-the-counter medicines, high-performing technology stock companies (so-called "FAANG"[1]) could not only start acting as insurance brokers but pivot into healthcare and insurance providers in their own right.

4.2 Smart Stadium as a Subset of Smart Cities

Prior to game day, well in advance of the actual event, sports fans and spectators of a live in-stadium event need to engage with the event organizer. In phase 1, the period prior to the event, the timespan between purchasing and securing an event ticket differs based on the profile of the fan. When an event participant is a season ticket holder or member, the interaction between consumer and event organizer

[1]Acronym for popular and high-performing tech stocks, namely Facebook, Amazon, Apple, Netflix and Google.

generally starts prior to commencement of the season. A purchaser of a single-event ticket, however, will engage closer to the actual time of the event. Leading up to phase 2, the actual event, shortly prior to commencement on game day, event organizers might provide useful information to the event attendee, covering the journey to the stadium, arrival, or admittance to the venue. Use of biometrics to administer entry to a venue or purchase concessions within an arena or stadium is one of the ways to simplifying and increasing throughput (https://www.clearme.com/sports/seahawks). On game day, fan experience can be improved by optimizing aspects of traffic flow using artificial intelligence and guiding fans to checkpoints by real-time push notifications. As such, questions on how to optimize the smart stadium can be viewed as a proving and validation process for the connected smart city.

For a long time, professional sports teams and event organizers have been trying to solve the dilemma of how to better engage with their fans who come and visit their game or event whilst statistically only having one name recorded for every 2.8 tickets sold. Even season memberships come with certain limitations, particularly when season ticket holders can pass on their seats to family or friends. In response, more and more venue operators are converting their ticketing systems from a paper stub to a digital ticketing platform via smartphone technology. The majority of professional sports teams now also offer a branded mobile app to access the venue and to get additional information whilst watching the event.

Of particular interest was a 2017 lawsuit of a fan against one of the teams in the National Basketball Association (NBA) in the United States. The fan claimed that the basketball team's official mobile app was eavesdropping on fans though a federal judge ultimately dismissed all charges (Wheeler 2017). According to privacy experts and advocates, the use of beacon proximity technology, in combination with the access permissions of apps, serves as a reminder to consider access details of an app. Importantly, event operators need to avoid alienating customers by secretively tracking their moves. Instead of creating a clandestine form of deep-state surveillance, incentive-driven engagement through raffles, rebates, or reimbursement could raise willingness of patrons to share preferences and data via apps or stadium-connected wearables.

In any case, modern stadiums with requirements for utility services, goods and merchandise movements, and infrastructure access, function as a small precinct within a larger metropolis. Embedded into the larger infrastructure grid, stadiums have to manage not only a particular baseline requirement but, more importantly, load management through periods of peak demand. As such, real-time and up-to-the-minute activity monitoring of a stadium status becomes essential to optimize fan experience and minimize the operating costs of a sporting and entertainment precinct (Fig. 5).

That batteries, repurposed from previously used electric vehicles (https://www.johancruijffarena.nl/default-showon-page/amsterdam-arena-more-energy-efficient-with-battery-storage-.htm) or similar energy storage systems (https://www.arsenal.com/news/3mw-battery-power-emirates-stadium), are being installed in order to provide vital back-up and peak power services for a stadium, highlight the efforts to

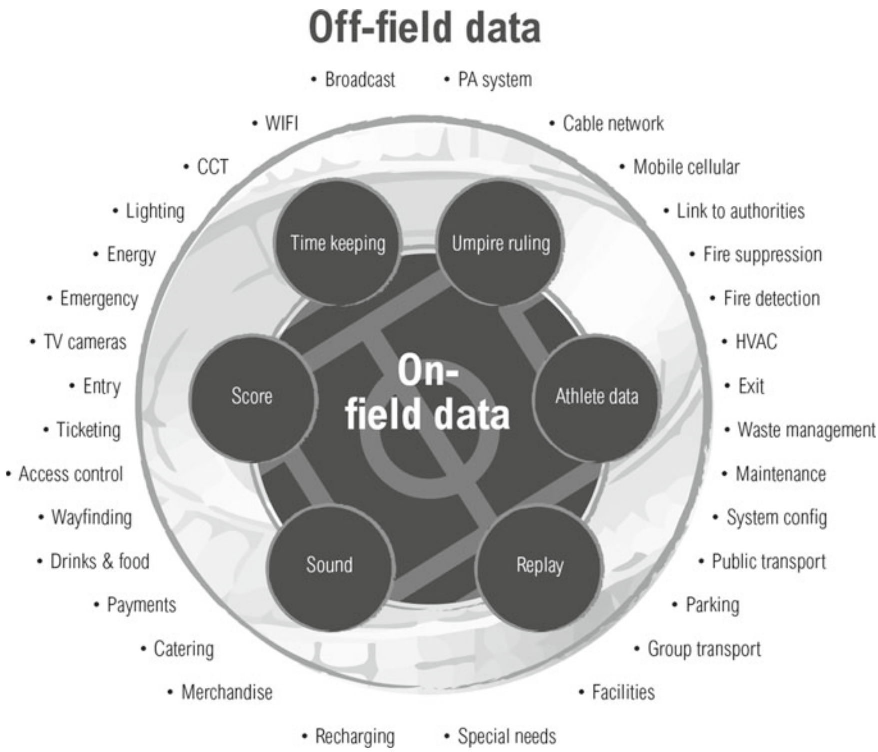

Fig. 5 Digital stadium platform

optimize operations. The venue operations, including infrastructure, safety, and security as well as sponsor operations and fan engagement, can potentially be optimized using a digital simulation approach. The future state of a digital twin stadium is expected to predict potential operational strains and proactively provide more efficient processes resulting in an improved service experience.

As the in-venue experience continues to compete with ever more sophisticated broadcast offerings, in-stadium camera arrays become increasingly important (https://www.intel.com/content/www/us/en/sports/technology/true-view.html). Multi-camera or sensor-based officiating technologies, such as goal-line technology (GLT) (https://football-technology.fifa.com/en/media-tiles/about-goal-line-technology/), video assistant referee (VAR) (https://football-technology.fifa.com/en/media-tiles/video-assistant-referee-var/), and virtual offside lines (VOL) (https://football-technology.fifa.com/en/media-tiles/fifa-quality-programme-for-virtual-offside-lines/) or 1st and Ten line display, provide the opportunity for in-stadium second screen applications—both on the large screen as well as on a personal smart device. In the future, it is imaginable that such officiating technologies will be projected onto or illuminated within the in-stadium field-of-play surface. In order for such advancements to become available, in-stadium high-bandwidth WiFi or next-generation wireless (5G) will become an essential requirement for venue-owners who seek to provide a high level of fan engagement. Such infrastructure could also provide value-add content to over-the-top (OTT) streaming services or traditional broadcasting. As a result, both the in-stadium experience and live sports broadcasting will continue to benefit from technological innovations that provide improved workflow and data analytics as an add-on to commentary and highlight production (https://frntofficesport.com/live-sports-broadcasting-spalk/).

A key aspect of the future in-stadium and broadcast experience will be the second-screen application with low or no latency. Whilst in-game betting is currently seen as both a commercial and an entertainment opportunity, not every patron might share the enthusiasm and expectations of punters. Therefore, other value-add service offerings should be integrated into the second-screen experience going forward. For example, instant, real-time in-game statistics derived from athlete tracking data, instrumented surfaces or equipment, and real-time coaching resources could be delivered to an individual's device. Such on-demand offerings could be integrated into different levels of ticketing price or membership structures. In addition to pre-configured sets of statistics, instant individual player statistics could pop-up as a user's device or glasses are pointed at a particular athlete or section of the field of play. Furthermore, patrons could become part of the game or broadcast by choosing camera angles, selecting a preferred commentator, or provide user-generated narration to live activity in the stadium. Such technological advancements could satisfy aspirations of the passionate super-fan, as highlighted in a recent UK survey (https://advanced-television.com/2020/01/16/survey-96-of-football-fans-want-personalised-tv-channels/). It is also conceivable that the live sporting experience could seamlessly integrate into the fantasy sport competition carried out during interruptions or intermissions of on-field activity. As such, a smart stadium could function as a platform for a real-time, in-stadium esports competition amongst fans and patrons. Furthermore, as governing sporting bodies see fit, umpiring reviews and other backstage activities could start to form a different, additional part of the playing rules even with official voting or scoring capability extended to patrons in the stands.

As previously stated, consolidation of in-games statistics, broadcast feed, and in-game betting or fantasy sport integration will require significant upgrade to in-stadium WiFi or next generation wireless network infrastructure. Such upgraded infrastructure, made available to managing concessions and merchandise, could also extend to IoT-enabled turnstile or patron access systems. Combined with the public–private data-cloud infrastructure and patrons opting into share data (see Fig. 2), new opportunities for sponsorship, partner promotions, or customer loyalty programs could arise; for example, in-stadium seating upgrades or personalized athlete-patron meet and greets could be exclusively offered on stadium entry.

4.3 Divergence of Media and Data Rights in Broadcasting

In 2018, the global sports media rights market was valued at a total of 49.5 billion USD (Sports Business Consulting 2018). According to the report, football (soccer) dominates the total global value with a share of about 40%, followed by American football, basketball, and baseball. However, overall, an increasing number of consumers no longer consume sports through traditional broadcast channels but use mobile devices to stream events. Driven by an increased globalization of fan engagement, on the one hand, consumers are prepared to subscribe to streaming services when their particular sporting event or favorite team's game is not available through the local broadcasting offerings. On the other hand, technology and telecommunication providers increasingly view sports rights as a way to attract customers to their infrastructure and networks. In some cases, due to the exclusivity arrangements of such broadcasting rights, consumers have experienced situations where major sports events or league broadcasts have been bundled with other services that the consumer would, otherwise, not have chosen.

Depending on the technology employed, current latency across a number of live-streaming applications is sometimes between 30 and 45 s and occasionally even longer whereas traditional cable broadcasters have a latency of five to ten seconds (Takahashi 2017) (see Fig. 6). Whilst such delay might not be too critical in relation to the viewing experience away from the live event or at home, it certainly can negatively impact the second-screen experience at a live sporting event as well as the wagering markets. This applies particularly to high-speed, circuit-based sports, such as motor sport and horse racing, and multi-site events such as golf, road cycling tours, as well as certain disciplines in athletics and ultra-endurance competitions. Accordingly, the quality of wireless network designs rather than price scrutiny will become a critical infrastructure consideration for

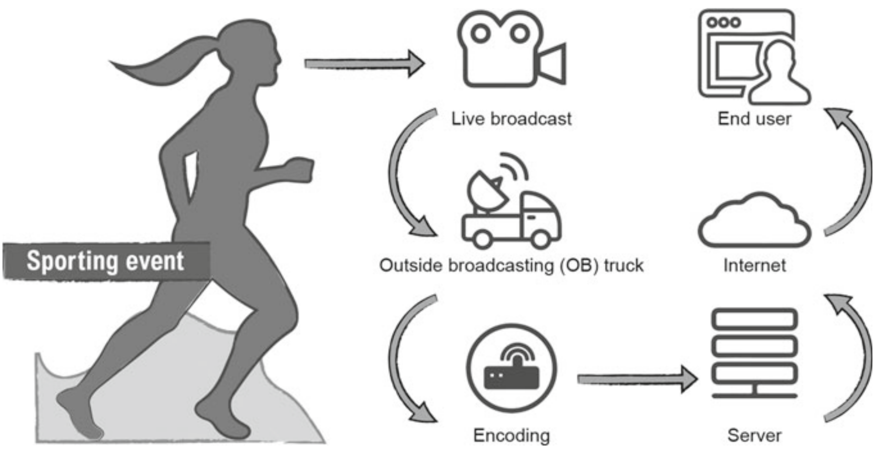

Fig. 6 Over-the-top (OTT) carrier streaming setup resulting in high latency

event organizers when providing high-speed WiFi-access to patrons in-stadium or at the stadium-perimeter (https://convergencetechnology.com.au) (e.g., a tailgating event).

Compared to traditional broadcast, OTT streaming offerings will become the preferred platform for both in-stadium and second-screen broadcast experiences. Low latency streaming will also avoid the time lag currently present between broadcast and social feeds. Ultimately, it is expected that sports data rights will be separately negotiated from broadcasting media rights. In particular, when it comes to deregulation of sports betting and mobile wagering applications, access to and provision of sports analytical data will become the driving force behind negotiations splitting data from media rights.

5 Diffusion of Knowledge: Translating from Sport into Other Verticals

5.1 Transfer from Sport to Allied Health

Sports technology can be viewed as a great validation platform for applications outside of sport and for knowledge diffusion into other sectors. Compared to highly regulated markets, such as medical technologies, sports technologies have somewhat lower barrier to entry. Sport applications, particularly in elite sport, typically center on human performance and injury prevention or rehabilitation. However, a move into fitness and wellness changes the focus to healthy living and lifestyle-related diseases such as obesity. Typically, non-professional athletes seek to achieve fitness and rehabilitation benefits, whereas elite athletes design their training activity to condition strength and prevent injury. When translating applications and technology solutions from elite sports to recreational fitness and wellness, regulatory complexity increases and the focus shifts toward assessment, monitoring, and treatment.

As a result of mapping performance of elite athletes, applications in human performance technologies can be validated in sports prior to transferring into the allied health market. Already today, fitness devices originally derived from elite sports are finding application in patient wellness or monitoring certain health conditions. Furthermore, sensors and devices can be integrated into retirement and nursing homes for the elderly. Beyond simple accelerometers, already in use to detect trips and falls, smart-insoles capturing cadence, step length, foot strike, pronation, and asymmetry could detect deteriorating changes in a patient's health conditions. It remains to be seen, however, if in the future, the number of sports technologies moving up the value curve will exceed the number of medical technologies being translated down the value curve into wellness and sport or vice versa.

5.2 Transfer from Sport into Occupational Health and Safety

As sport applications generally center on human performance, it is also plausible that sports technologies can be further translated into other sectors including occupational health and safety (OH&S) (see Fig. 7). Advanced materials used in sports apparel or protective gear to improve performance or prevent injuries can be translated from sport into occupational health and safety. Beyond advanced materials, it is plausible that motion sensors and devices that map skill execution in sport can also play a role in posture or load management. Already today, devices with accelerometers, gyroscopes, and magnetometers derived from sport are used to monitor problematic postures, repetition of movement, and muscle activity in challenging workplace conditions (https://www.dorsavi.com/us/en/visafe/). In the future, such devices can also be credibly deployed in situations where employers, health professionals, and insurers or regulators need to administrate back-to-work plans following a worker's injury or workplace accident.

Such technology transfer could extend beyond the translation of sensors and devices to software analytics, dashboards, and predictive algorithms. As machine learning and artificial intelligence algorithms in sport evolve from "sense and respond" to "predict and act," such models probably could also assist accident

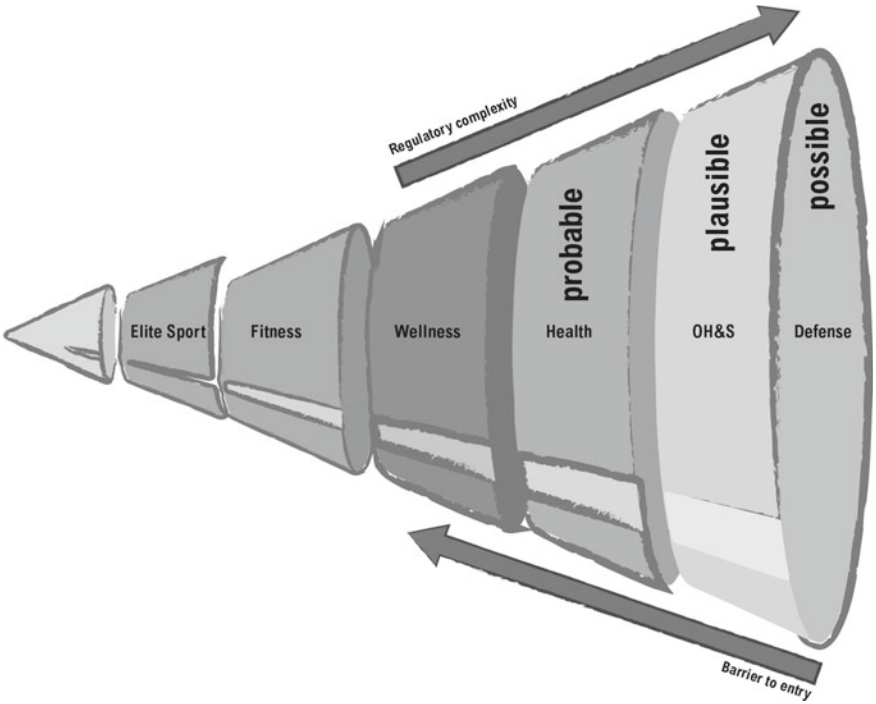

Fig. 7 Technology translation from sport to health, OH&S, and defense

prevention in the workplace. As the fourth industrial revolution progresses on the manufacturing shop floor, it is feasible that predictive athlete load models could be combined with machine and manufacturing line simulations to form a true digital twin of complex human–machine interactions. Furthermore, based on such digital-twin models, augmented and virtual reality (AR/VR) applications used in sport to simulate reoccurring maneuvers on the field of play could then be deployed in workplace-related operations training, skill-development, or hazard prevention scenarios.

5.3 Transfer from Sport into Defense

In a similar way, it is also possible for solutions validated in sport to extend into defense applications. Questions of load management of an athlete or impact protection are some obvious examples where innovations in sport can be used to diffuse knowledge from sports into defense. For example, a recent case study outlined how a device measuring athlete loadings could be deployed in balancing loads and strengthening infantry soldiers (Lakhani et al. 2019).

Beyond advanced materials and sensors and devices, behavioral and cognitive technology solutions could easily translate from sports to defense. Applications that assess or measure decision-making under duress, bioelectric memory stimulation, and deep learning are some of the possible applications that can be first validated in sports. Furthermore, advances in the science of nutrition, sleep, and ultra-endurance sporting activity seem destined for knowledge diffusion into defense.

There is potential for sport and defense to work together to vet and validate new technologies—this seems particularly true for extreme and e-sports. For example, the Air Force could collaborate with BASE-jumpers to validate wingsuit design and material with the aim to translate findings into aircraft pilot or parachute equipment. For Army personnel, it is entirely feasible to work with mixed martial arts, for example, the Ultimate Fighting Championship (UFC), to evaluate strength and conditioning regimes and techniques to improve consciousness, alertness, as well as mental toughness. Whilst seemingly a cliché, methods trialed in esports to improve cognitive, responsive, and agile behavior important in the preparation of esports athletes could similarly prepare military operators of unmanned aerial vehicles for military intervention. Such collaboration could include personnel training, analytics, and data monitoring of human–machine interaction.

In summary, sports technologies are closely aligned with capabilities and advancements in other sectors, like advanced manufacturing, physics and electronics, medicine and biotech, and information technologies (see Fig. 8). In order for sport and industry to collaborate, aspects of digital service provision, development of new business models, and open innovation become integral prerequisites in that translation journey. This translation journey requires that sport organizations and technology providers merge industry and Internet culture, focus and set priorities, and value security and customer privacy when dealing with athletes of all abilities. Nevertheless, two large challenges remain: First, to develop truly open

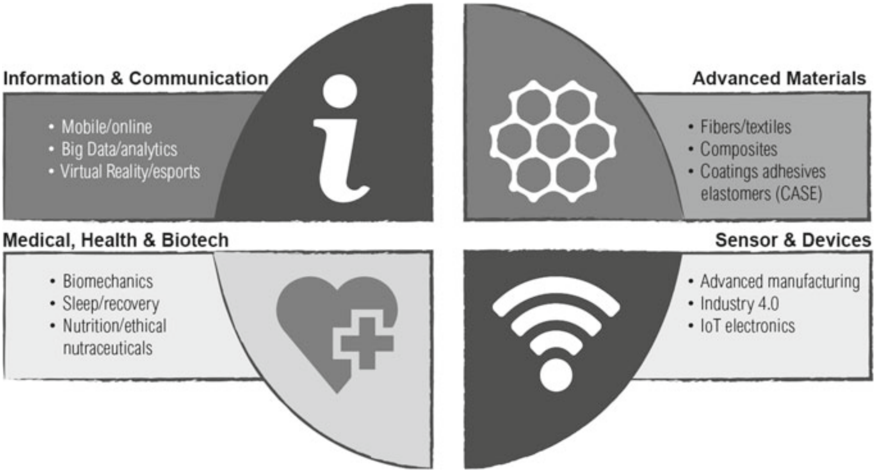

Fig. 8 Areas and aspects of sports technology

standards and provide suitable application programming interfaces (API) for necessary data exchange and collaboration, instead of attempting to lock customers into proprietary platforms and solutions. And, second, to respect data privacy and incentivize data sharing rather than deploying a clandestine form of deep-state surveillance.

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Craig Hill is a leading sports technology specialist in Australia with connections to global sports markets. He is currently engaged in a number of roles across sports technology investment and advisory including Special Projects at the Australian Sports Technologies Network (ASTN). Craig co-founded the ASTN in 2012 and was the inaugural Executive Director until 2017. He led the development and implementation of a suite of programs to support the development of the sector including international trade missions, start-up accelerator programs, conferences, and international partnerships. He enjoys playing, coaching, and watching his two children enjoy a variety of sports such as basketball, Australian rules football, and soccer.

The Future of Additive Manufacturing in Sports

Daniel Beiderbeck, Harry Krüger, and Tim Minshall

Abstract

This chapter highlights the present and projected impact of additive manufacturing technologies on the sports ecosystem. Beiderbeck, Krüger, and Minshall first describe the process- and product-related advantages that derive from additive manufacturing in general. Then, they introduce an additive manufacturing sports application matrix, which serves as a grid to structure current use cases along their benefits for the sports industry. Next, they illustrate how the interplay between additive manufacturing and technological advancement in other fields like artificial intelligence, sensor technology, and robotics can create new products and business models. The chapter concludes with a discussion about future opportunities and challenges around additive manufacturing and innovation in sports.

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1 Development of Additive Manufacturing

In the 1980s, a revolutionary technology entered the production ecosystem: Additive manufacturing (AM). Officially defined as "a process of joining materials to make objects from 3D model data, usually layer upon layer," AM allows for fundamentally different processing principles compared to traditional subtractive manufacturing methodologies like turning, milling, and grinding (Hopkinson et al. 2005). The revolutionary characteristic of this technology is producing directly from a computer-based model. While conventional procedures either chip material to obtain a certain shape or require prefabricated molds, AM *creates* structural elements layer by layer (Gebhardt 2012). Thus, the basic principle is to slice any given geometric form into layers before reconstructing it from these layers (see Fig. 1) (Gibson et al. 2015). Advantages of this disruptive technology include an almost unlimited freedom of design, less waste, as well as the potential to fabricate parts on-location and on-demand (Atzeni and Salmi 2012; Beiderbeck et al. 2018). At this point, it should be mentioned that AM is sometimes referred to as 3D printing but, strictly speaking, this synonymous use is wrong. 3D printing actually describes a subset of the larger group of AM technologies, however, the term has been established in general public.

In its early years, AM was mainly used for prototyping purposes (Bourell et al. 2009). Companies used the technology to produce single parts or models in a more cost-efficient and less time-consuming manner. The elimination of several steps along the value chain compared to traditional manufacturing methods (see Figs. 2

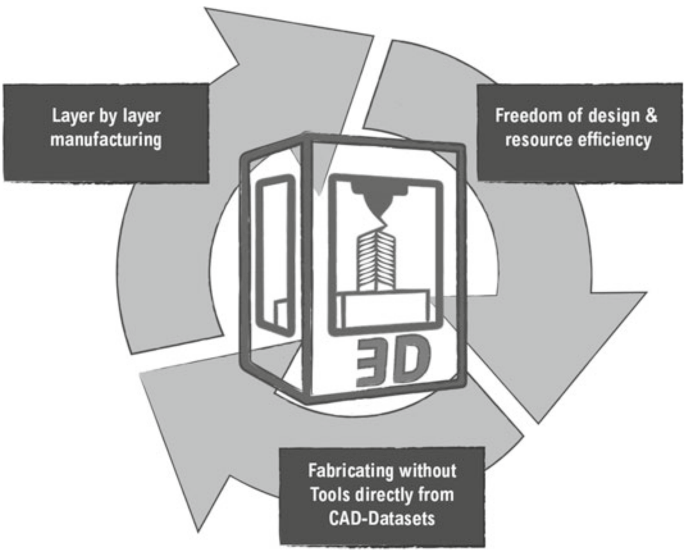

Fig. 1 AM process advantages

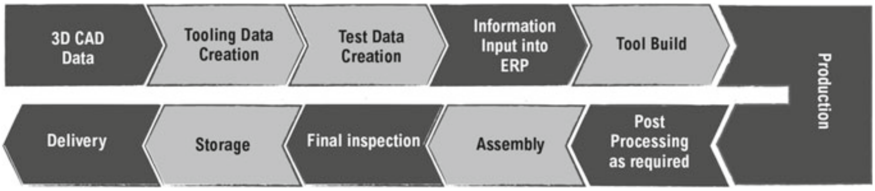

Fig. 2 Traditional manufacturing value chain

and 3) led to a faster production process and thus, the term *rapid prototyping* emerged (Beiderbeck et al. 2018). With the beginning of the twenty-first century, AM began to spread to a wider range of applications, including the direct manufacture of products, sometimes referred to as *rapid manufacturing* (Kaldos et al. 2004). Also, the range of engineered materials increased over the years, starting from predominantly plastics (Stansbury and Idacavage 2016) to metals, ceramics (Todd 2017; Owen et al. 2018) and nontraditional materials, including organic cells or tissues (Murphy and Atala 2014).

The increasing flexibility in terms of materials and quality improvements helped AM penetrate the world of manufacturing. Early on, high-end sectors like the aerospace or automotive industries discovered the potential of AM to create competitive advantage. Particularly the freedom of design and the ability to process light-weight materials enabled the development of new, innovative products that could not be manufactured by traditional methods (Kyle 2018). In fact, AM revolutionized the fabrication of free-form structures, functional integrations, and novel structural solutions. These production characteristics also allowed AM to contribute to the field of *mass customization.* Especially in areas like the medical or dental industry, in which patient-specific customization of products is valuable, AM has demonstrated its advantages (Deradjat and Minshall 2017). These benefits similarly apply for industries that deal with small volumes and high-value parts, such as the aforementioned aerospace and automotive industries (Liu et al. 2017).

Also, with respect to sports, AM can play a vital role. Many scholars agree that most future performance improvements will result from technology innovations and applications (Balmer et al. 2012; Dyer 2015); and AM has already started to contribute significantly—especially in motorsports and sports equipment (Cooper et al. 2012). In general, AM offers a wide range of opportunities in sports technology, since this sector combines the customization requirements of the medical or dental industry with the high-value facet of aerospace or automotive (Kajtaz et al. 2019). In the past, most use cases focused on elite sports, given the high cost and relatively slow processing speed in larger volumes. These challenges hold true for most AM applications; the technology has yet to live up to expectations with regard to *mass production*. But further improvements can be seen on the horizon and the sports industry will be among the first to benefit. The following sections will explore the current state of AM in sports in greater detail and dig deeper into potential future use cases both for elite sports and the broader sports ecosystem.

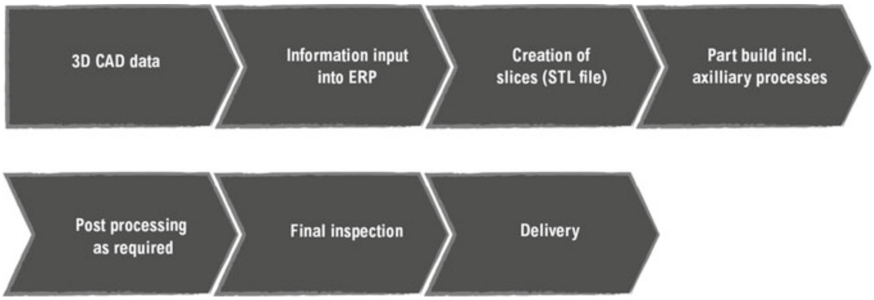

Fig. 3 AM value chain

2 Additive Manufacturing in Sports Today

Given the wide range of (potential) AM applications in sports, it appears appropriate to structure the current and future AM business opportunities along different criteria. Therefore, we introduce the *AM Sports Application Matrix* (see Fig. 4), which helps to categorize and locate different AM use cases in sports.

2.1 AM Sports Application Matrix

One dimension of our *AM Sports Application Matrix* aims to describe the different benefits that sports organizations and athletes or consumers can generate from the use of AM (x-axis). Sports organizations may include specialized sports manufacturers as well as multinational apparel companies in the sporting sector. By athletes we mean both professional and casual athletes, so applications from high-end equipment to wide-range products for a mass-market apply. Similarly, this group includes consumers who do not actively do sports, but who experience sports in a different way thanks to AM applications. Having these classes of beneficiaries in mind, there are five possible areas of utility: (1) *Cost efficiency*, (2) *performance*, (3) *health & safety*, (4) *new experience & design*, and (5) *sustainability*. While the first category mainly focuses on the benefits for retailers and manufacturers, categories 2-4 describe benefits for immediate use by athletes and consumers. In general, this distinction between added value for producer or user appears appropriate, because it implies a positive business case behind any given application. Category 1 assumes an unchanged utility while allowing the producer to decrease cost (*design for cost*). The use cases that serve categories 2-4, in turn, will create additional value for the buyer (*design for value*), thus justifying a price premium. The sustainability aspect is somewhat special; it is highly relevant in today's time and, presumably, even more important in the future (Despeisse and Ford 2015). On the one hand, if a product is fabricated in a sustainable way, it might increase

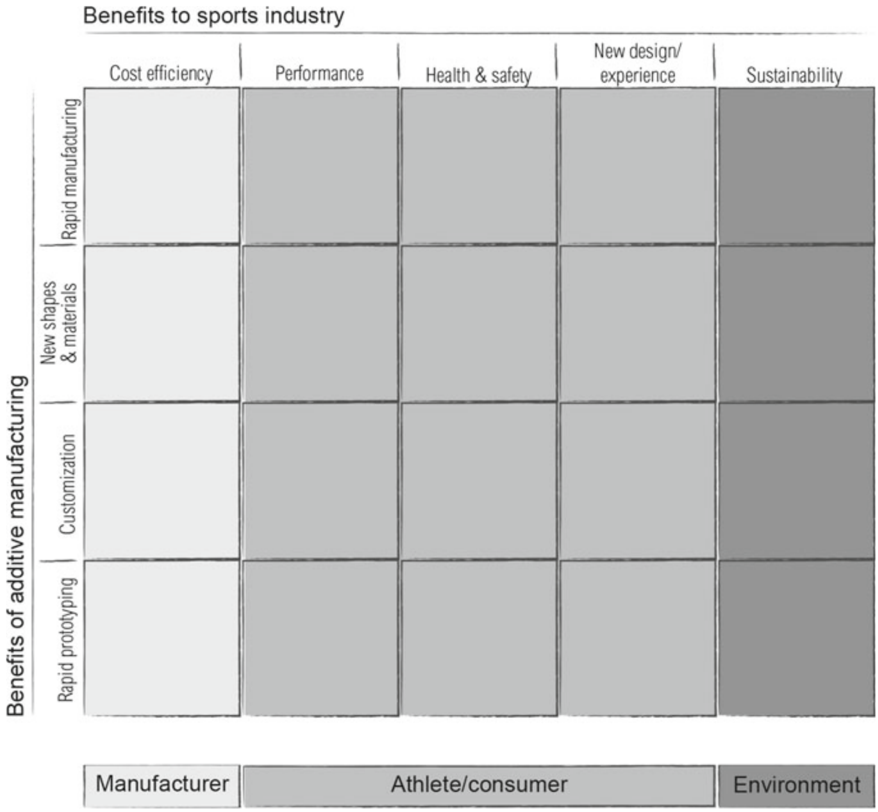

Fig. 4 AM Sports Application Matrix

buyers' willingness to pay. On the other hand, there might be different or additional incentives for manufacturing companies to focus on environmental aspects, be it subsidies for sustainable production or an act of corporate social responsibility. No matter what, this aspect surely counts as a potential benefit to the sports industry.

All in all, the five categories holistically cover the wide range of possible benefits a new technology can bring to the sports sector. However, these categories are, in fact, independent of any technology. One could easily imagine other technologies like robotics, virtual reality, or connected devices creating value in exactly these dimensions. Therefore, to look at it through the lenses of AM, we added a second dimension to this technology-agnostic framework. This dimension describes the potential benefits that arise from the specific technology (y-axis). With respect to AM, these benefits include process advancements like *rapid prototyping* and *rapid manufacturing*, as well as product advancements like *customization* and *new shapes & materials*. These four categories, described in the first section of this chapter, were arranged based on the stage in which they unfold their potential.

For example, rapid prototyping is typically the first area of application and customization and the deployment of new shapes and materials follow. Rapid manufacturing often comes as a last step to scale up productivity of iterated and optimized items.

2.2 The Rise of AM Use Cases in Sports

Not unlike other industries, the rise of AM in sports started with *rapid prototyping*. Sports apparel giants like Nike and Adidas officially started in 2012, fabricating additively manufactured prototypes of shoes, which allowed them to reduce production time significantly. While Nike reported to have a 16-times faster prototyping process, Adidas shortened prototype production from 1 to 2 months to less than a week.[1] Next to time advantages over traditional manufacturing methods, AM also provided 10% cost efficiency at Nike, estimated by Morgan Stanly in 2017.[2] By that time, both Nike and Adidas began to advance into *rapid manufacturing*, offering mass-market footwear produced with AM technology.[3] Nike then filed a series of patents, together with their partner HP, to protect the products produced by HP's 3D printers. Similarly, Adidas started a cooperation with the 3D printing company Carbon to accelerate their mass-market production of additively manufactured footwear.[4] In 2020, not only Nike and Adidas but also other sports apparel companies like Reebok, PUMA, Under Armor, and New Balance—among others—offer 3D printed shoes;[5,6] In most cases, they partner with AM technology providers, which have started to develop own products and establish new brands.[7] For example, there are now companies offering customized ski boots to ensure maximum fit or individualized ballet shoes to reduce pain and injury for dancers.[8,9]

Although there are many more examples of additively manufactured products in the sports industry, described subsequently, footwear serves as an excellent example as it shows the evolution of AM utilization (see Fig. 5). Some of the most innovative companies in sports business realized the technology's potential and started with prototyping use cases that clearly provided time and cost benefits (step 1). Then, the technology allowed for first steps of customization (step 2).

[1]https://www.ft.com/content/1d09a66e-d097-11e2-a050-00144feab7de

[2]https://www.forbes.com/sites/greatspeculations/2016/05/18/heres-how-nike-is-innovating-to-scale-up-its-manufacturing/#335ab3801497

[3]https://www.adidas-group.com/en/media/news-archive/press-releases/2015/adidas-breaks-mould-3d-printed-performance-footwear/

[4]https://www.adidas-group.com/en/media/news-archive/press-releases/2017/adidas-unveils-industrys-first-application-digital-light-synthes/

[5]https://www.sporttechie.com/new-balance-working-3d-printing-company-develop-high-performance-running-shoes/

[6]https://3dprintingindustry.com/news/reebok-releases-liquid-factory-3d-printed-floatride-run-sneakers-u-s-131033/

[7]https://all3dp.com/topic/3d-printed-shoes/

[8]https://www.tailored-fits.com/en/

[9]https://all3dp.com/4/3d-printed-ballet-shoe-p-rouette-reduces-pain-injuries-dancers/

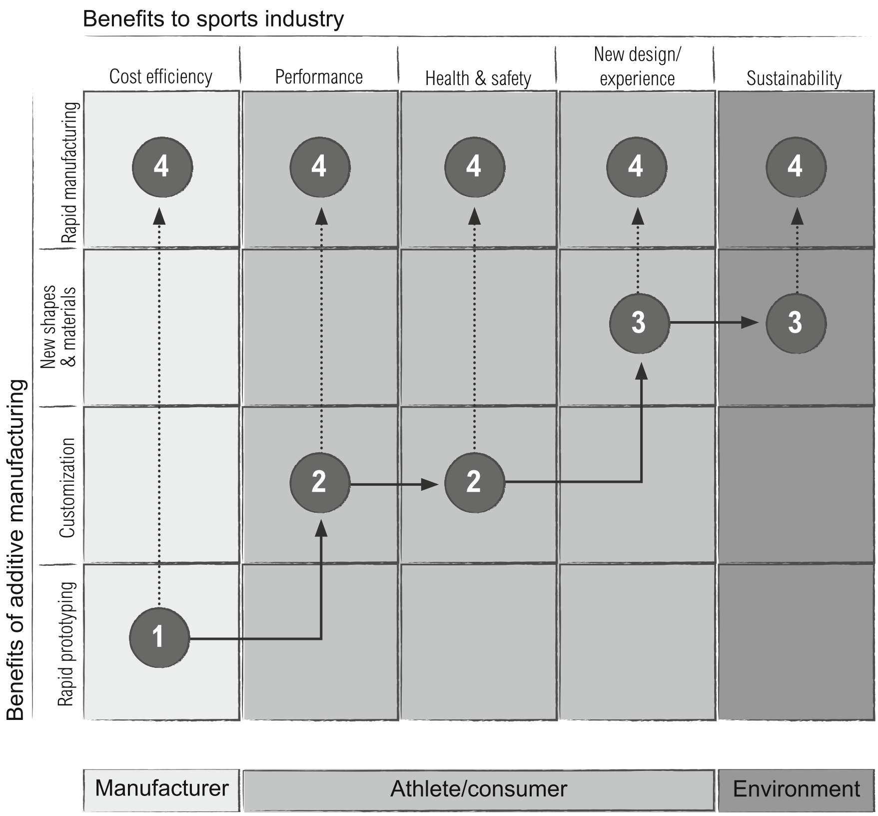

Fig. 5 Application stages of AM in the sports footwear industry

Use cases include orthodontic insoles that were included directly in the shoes—football cleats, for instance—providing advantages in terms of performance as well as comfort, health, and safety. Applications with new material and shapes followed (step 3). For example, Nike produced unique running shoes with 3D-printed uppers for Kenyan elite long-distance runner Eliud Kipchoge, which were completely water-resistant and pushed performance to the limit.[10] Eventually, findings from elite sports were transferred to mass production, offering additively manufactured trainers to a wider customer base (step 4). In this context, the sustainability potential of AM also came into play. In 2015, Adidas started a collaboration with Parley for the Oceans, producing 3D-printed footwear prototypes made of ocean waste.[11] Over the past few years, this idea turned into a market-ready collection, selling

[10]https://news.nike.com/news/eliud-kipchoge-3d-printed-nike-zoom-vaporfly-elite-flyprint
[11]https://www.adidas-group.com/de/medien/newsarchiv/pressemitteilungen/2015/adidas-und-parley-oceans-setzen-paris-ein-zeichen/

more than 10 million pairs in 2019 with customers willing to pay a significant extra for the environmental contribution.[12]

Taking these developments into account, AM already plays a role in the industry. However, given a total market size of athletic footwear of about EUR 65 billion in 2020 and a year-on-year growth of 8.3%, there is still a lot of opportunity for AM products to capture more market share in the future.[13] Experts predict that by 2030, 10% of sports footwear will be fabricated with the help of AM, of which 90% will be mass products. Assuming stable industry growth, this would result in a EUR 14.4 billion market for additively manufactured sports footwear in ten years—not considering fashion shoes, which are also an interesting field of opportunity for AM technologies.

2.3 Current AM Use Cases in Sports

As mentioned, there are also several other applications in sports that go far beyond footwear. In this chapter, we want to give an overview of the most relevant use cases (see Table 1) and locate them on the AM Sports Application Matrix, to get a better feeling of where AM currently takes place in the sports industry (see Fig. 6). While this list is not meant to be fully exhaustive—almost impossible given the speed of innovation in the field—the selected top-30 use cases cover the largest and most relevant areas of application. These areas of application can be sorted in four major clusters: footwear, equipment, personal protective apparel (PPA), and other applications.

The most relevant category, next to footwear, is certainly sports equipment, which is reflected in the number of use cases that can be found today. Equipment includes everything necessary to pursue a certain sport excluding clothing, wearables like mouthguards, etc. Thus, the equipment comprises bikes and components of bicycles, skis and bindings, golf clubs, tennis rackets, and so on. This category would also include the various applications found in motorsports. However, additively manufactured parts for motorsports are neither listed nor considered in our matrix as these would go beyond the scope of this chapter. It should still be mentioned, that AM has a wide range of applications in motorsports especially when it comes to lightweight structures for racecars and motorbikes (Cooper et al. 2012). Personal protective apparel, as a third category, also benefits significantly from AM. For example, with AM helmets, mouthguards, shin guards, and other protectors are customizable.

The category of other applications includes, inter alia, everything that is related to protheses—a field with immense growth and high relevance both in professional and recreational sports. The category also comprises training devices like golf putting trainers, training masks that simulate high altitude breathing, exact copies of

[12] https://www.edie.net/news/5/Adidas-to-double-production-of-ocean-plastic-trainers-for-2019/
[13] https://www.statista.com.login.bibproxy.whu.edu/outlook/11020000/100/athletic-footwear/worldwide

Table 1 Current AM use cases in sports

	#	Use Case	Description	Companies [not exhaustive]
Footwear	1	**Running shoes**	Mainly customized running shoes with focus on additively manufactured midsoles and insoles. In some cases, also 3D-printed uppers. AM allow for fast and individualized production.	adidas, Nike, Reebok, New Balance, Under Armor, PUMA, HP, Carbon, AM equipment manufacturers
	2	**Cleats**	Shoes for all types of ball sports with integrated and customized insoles. In some cases, also 3D-printed spikes. AM allows for mass customization at relatively low cost (economical up to a size of 30).	adidas, Nike, New Balance, Prevolve, AM equipment manufacturers
	3	**Trainers and snea-kers**	Footwear for casual use. Often with 3D- or 4D-printed design elements. AM allows for mass customization and production with environmentally-friendly materials.	adidas, Nike, Reebok, New Balance, Under Armor, Oli-ver Cabell, AM equipment manufacturers
	4	**Ski boots**	Individualized ski boots built based on 3D-model of the feet. AM allows for ideal comfort and optimal transmis-sion of forces.	Tailored Fits AG, Materialise
	5	**Ballet shoes**	Fully individual ballet shoes with special forms to reduce pain and injuries for dancers. AM allows for rapid prototyping and customization.	P-Rouette
Equipment	6	**Bikes**	Completely printed bike frames, for example for road bikes. AM allows for lightweight materials and stiff structures.	Arevo, ColorFabb, Renishaw
	7	**Bike com-ponents**	Different parts of the bike, for example, trailblazing bike hubs, or personalized handlebars. AM allows for lightweight materials and improved endurance.	EOS Kappius, Erpro & Sprint, GIE S2A
	8	**Horseshoes**	Customized titanium horseshoes for racehorses. AM allows for perfect fit, curing chronic foot diseases like Laminitis.	CSIRO
	9	**Wheel-chairs**	Lightweight wheelchairs used for elite sports at Paralym-pics. AM allows for fabrication of tailor-made seats as well as wheelchair racing gloves.	Loughborough University
	10	**Golf clubs and balls**	Highly individualized golf clubs with 3D-printed design elements. AM allows for mass customization as well as 3D-printed golf balls and tees that can be printed at home.	Callaway Golf, Titomic, Krone Golf, Grismont Paris, Nike
	11	**Tennis rackets**	Fully customizable tennis racket handles. AM allows for maximum robustness and reduced weight, provides precision grip for the tennis player.	Unstrung Customs, Ogle Models, CRP Technology
	12	**Fencing hilts**	Personalized nonslip hilts for a fencing foil. Developed by researchers and used during the London Olympics. AM allows for customized fit at low cost.	University of Tsukuba
	13	**Lacrosse stick heads**	Optimized lacrosse stick heads. AM allows for rapid prototyping and faster product-to-market cycles. Helps new competitors to quickly win market share.	University of Bath, String-King, STX, Warrior/Brine

(continued)

Table 1 (continued)

Equipment	14	**Skis**	Fully functional skis. AM allows for customization and processing of new materials to create new skiing experience.	Stratasys
	15	**Snowboards**	High-quality snowboards with advanced stability. AM allows for production of sustainable boards with less plastic and new designs.	Burton, CIME Industries
	16	**Bindings**	Step-in (strapless) system for snowboard bindings. AM allows for rapid prototyping and cheaper production.	Burton
	17	**Rifle grips**	Fully customized rifle grips. AM allows for rapid prototyping and perfect-fit grips based on 3D models of the athletes' hands.	Athletics 3D, Zortrax
	18	**Sleds**	Tailored sleds for athletes. AM allows for perfect tooling and customization. Team USA won 2018 Winter Olympics in PyeongChang with the help of AM.	Stratasys
Personal Protective Apparel (PPA)	19	**Helmets**	Smart helmets provide more comfort and more safety. AM allows for new structures and materials as well as perfect fit customization.	ACEO, Carbon, Riddell, Hexo Helmets, Kupol
	20	**Faceguards**	Customized faceguards and masks protect players. AM allows for perfect fit and safety, also provide protection for players who suffered face injuries before.	Cavendish Imaging, RMIT University
	21	**Mouth-guards**	Individualized mouthguards with extra functionalities. AM allows for mass customization and integration of additional features like squeezable pods for hydration of athletes.	GRiTT 3D, Hydra-guard, Guardlab
	22	**Shin guards**	Fully functional shin guards. AM allows for mass customization, provide perfect fit and higher comprehensive protection.	Zweikampf
	23	**Chest protection**	Individualized chest protectors. AM allows for perfect fit and thus, maximum safety with minimum weight.	University of Zagreb
Other	24	**Protheses**	Individualized protheses for disabled athletes. AM allows for perfect fit as well as faster and cheaper production.	Autodesk
	25	**Golf putting trainer**	Customized exoskeleton to improve body posture when putting. AM allows for individual fit and cheap production of exoskeletons.	3D MedScan
	26	**Training mask**	Special mask to simulate high altitude training. AM allows for rapid prototyping and faster development cycle.	Reebok
	27	**Earbuds**	Customized earbuds for recreational athletes. AM allows for mass customization based on 3D in-ear scans.	Normals
	28	**Mountain imitations**	Climbing holds for professional and recreational climbers. AM allows for cheap production and perfect replication of real mountain trails.	Force Climbing
	29	**Athlete mannequins**	Physical replicas of athletes. AM allows for fast and precise production at low cost. Mannequins can be used as merchandising articles or as research objects to improve aerodynamic of clothes for a professional cyclist.	TU Delft, Printstrike
	30	**Smart clothes**	Reactive clothing that responds to sweat, heartrate and other triggers. AM allows for integration of sensors and actors in clothes.	Chromat, Intel

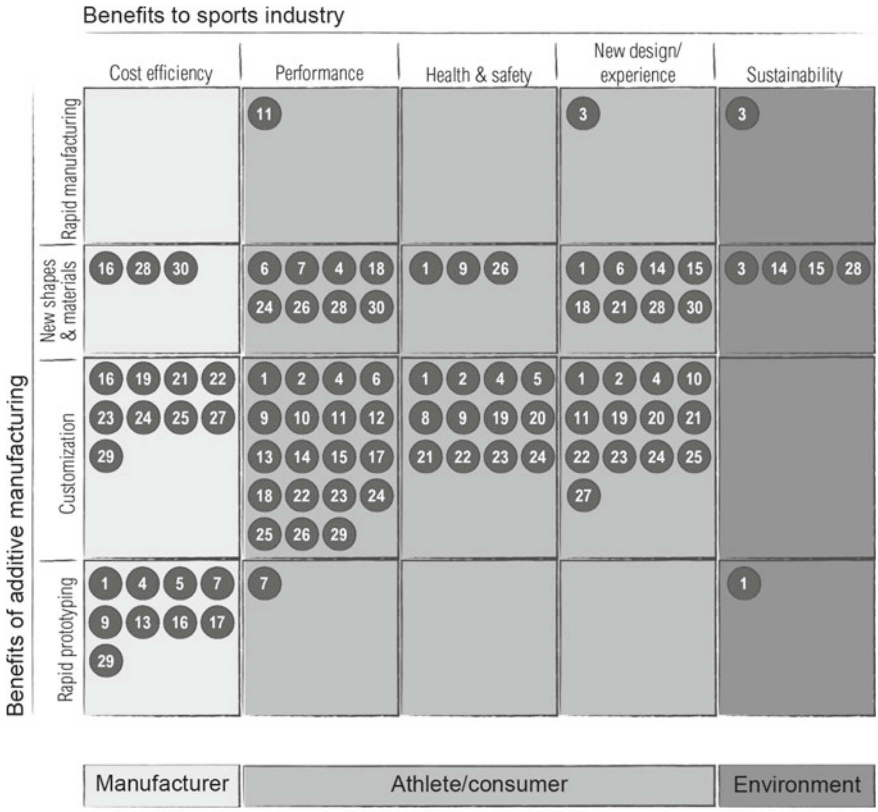

Fig. 6 Current AM use cases in the AM Sports Application Matrix

mountains for climbers to train climbing routes in a safe environment, and earbuds that are perfectly customized for their users. Albeit futuristic-sounding, smart clothes are also produced by AM. For example, there is a prototype of a sports bra that includes 3D-printed parts, sensors, and a computer chip to measure temperature, breathing, and perspiration that opens or closes vents in the bra to prevent sweating. Although this was just a fashion prototype, it shows the almost unlimited possibilities that AM can create in combination with other technologies.

Regarding the companies mentioned in Table 1, it must be noted again that most retailers or sports equipment manufacturers cooperate with the leading AM companies like 3D Systems, Carbon, EOS, FormLabs, HP, Materialise, Nanoscribe, Proto Labs, SLM Solutions Group, Stratasys, Ultimaker, and Xaar, among others. These should definitely be named as they often drive the technical development and even appear with their own AM products in the sphere of sports and sports equipment.

A closer look at the use cases located on the AM Sports Application Matrix reveals that most of the current application benefit comes from the ability to customize products with AM technologies (see Fig. 6). In particular, this allows athletes to improve their performance, protect them from injuries, and provide them a new experience in terms of comfort or design. The matrix also shows that there is further potential for AM to be used as a large-scale production technology. However, this obviously requires further development and a decrease in manufacturing cost for high volumes, compared to traditional fabrication processes.

The question remains, however, how fast and to what extent the sports industry will seize AM-related opportunities. To get an idea of what might be possible in the future, the next section will describe the fictional use case of biathlon in 2030 and illustrate how athletes and spectators might benefit from AM technologies.

3 Future Use Cases of Additive Manufacturing in Sports

It is 2030 and Julia just became the new biathlon champion of the Winter Olympics. While standing on the winner's podium, she knows that she could not have won the competition without her fully customized biathlon equipment. Recent advancements in AM, artificial intelligence (AI), and sensor technologies allow Julia to reach consistently her performance limits. She knows that her sport has changed tremendously over the last decade. This particularly holds true for biathlon equipment, which has to adapt to the athlete's requirements under every condition to ensure best performance as well as the highest safety standards.

3.1 Impact of Biathlon Equipment on Athlete's Performance

Julia's performance and safety are largely dependent on the degree of customization of her equipment to her individual needs. In the following overview, we provide examples of the importance of customized equipment in biathlon:

- First, biathlon **footwear equipment** (ski boots and skis) is crucial for skating performance. The ski boot is the direct connection between Julia's feet and her skis. A perfect fit ensures the best force transmission on the ski (i.e. highest performance) as well as maximum comfort and safety. Furthermore, the ski represents the direct link between Julia's ski boots and the ground (i.e., the skis bring her performance onto the slope). Thus, the skis must have the right size and geometry (e.g., length, width, curvature, etc.) as well as the right material (e.g., weight and weight balance, interaction with snow, etc.) to ensure Julia's maximum performance. Obviously, the right configuration of her skis also depends on various environmental factors; AM allows Julia to print her perfect gear right before the race.
- Second, the biathlon rifle (**biathlon specific equipment**) is critical for the athlete's shooting performance. For Julia, it is crucial that her rifle fits perfectly to her body. For example, the rifle's geometry must fit to the shape of her arms to

ensure a precise grip; the rifle's weight balance must fit to her grip to ensure a controlled pointing on the target; the rifle's geometry must fit to her eyes to ensure a precise targeting and shooting.

- Third, Julia has a variety of **other equipment**, where she can benefit from customization. For instance, individual ski poles that improve force output based on Julia's physical constitution and exact slope conditions (Killi and Kempton 2018). Or customized sports sunglasses that allow for high-wearing comfort as well as a stable fit, which might influence Julia's shooting performance. Furthermore, her clothes could also be customized, allowing for a more aerodynamic fit. Lastly, individualized summer training gear could allow a high-performance training in the summer with simulated winter conditions.

These examples should illustrate that a biathlon athlete could greatly benefit from a customized equipment set. Additionally, it must be highlighted that an athlete's individual requirements on his equipment might change over time. Reasons for this could include a change in physical shape due to age, injuries, or even growing muscles. Also, movement patterns might vary based on fitness level or environmental conditions such as weather, temperature, humidity, and altitude. Thus, a biathlon athlete definitely has a continuous need for customized sports equipment.

3.2 New Solution: Smart AM for Biathlon Equipment

In 2030, the Smart AM solution enables Julia to train and compete with her fully customized gear. A combination of AM and other technologies like AI and smart sensors create and produce Julia's customized biathlon equipment in three major steps:

1. In the first step, **a broad set of data is collected** via smart sensors to capture athlete-specific parameters. The following types of data are collected:

   - Static data: Static data is data about the athlete's size and body structure, which are regularly collected with a 3D body scan. These data points are important to ensure the perfect fit of her equipment, e.g., biathlon rifle grip perfectly fitted to her hand, shoulder and back, or ski boots completely tailored to her feet.

   - Dynamic data: Dynamic data is data about the athlete's motions, which are recorded via smart sensors in the equipment and by cameras. For instance, acceleration sensors in skis record the movement of each ski and the skating style of an athlete. Again, this style might vary under different endogenous and exogenous conditions. Furthermore, pressure sensors along the skis record the transmission of forces from the respective ski to the ground. Another example is sensors in the rifle that record its orientation and positioning. All this information is relevant to understand the athlete-specific biathlon style.

- Performance data: Data about the athlete's performance such as average speed, high speed, shooting performance, heart rate, etc., is recorded. These data are recorded by different means, such as through a camera in her glasses, GPS sensors, a heart rate sensor, and sweat glands sensor.

The combination of these three data sets is relevant to understand Julia's specific needs regarding her performance. While the performance data says whether the athlete performs well, the static and dynamic data provide an overview of the athlete-specific characteristics. The combination of these three data sets determines whether the athlete's equipment is fully customized to the athlete's needs.

2. In the second step, an **AI model leverages the collected data** and derives perfectly customized biathlon equipment. In particular, the AI model translates the data sets into geometric information for the equipment. For instance, the AI model derives the perfectly customized length and curvature of the biathlon skis from the athlete's speed performance, individual ski movements, and weather conditions. In another example, the AI model derives the perfectly customized geometry and weight distribution of the rifle based on the athlete's shooting performance, positioning, and orientation of the rifle. The output of the AI model is a fully customized CAD model of biathlon equipment considering all accessible datapoints.
3. In the third and last step, **AM produces the customized biathlon equipment** based on the generated CAD model. As stated earlier, AM has various advantages that make it the perfect manufacturing method for Julia's customized gear; the ability to produce components, test them, and iterate the design before producing another prototype is unparalleled in the world of manufacturing. The iterative optimization of sports equipment is only feasible with AM. Assuming that algorithms have the potential to optimize an athlete's performance, the symbiosis of AI and AM will play a definitive role in the future of competitive sports. While some applications might already be possible today, short-term response to changes regarding the athlete and/or the environmental conditions is simply impossible with current technology; in the future, only AM will allow instant fabrication on-site.

3.3 Smart AM in Other Professional Sports

Biathlon is only one case in which professional athletes can benefit from a smart AM solution. There are many other examples in professional sports where it is important that the athlete's equipment is fully customized to his needs. In tennis, for instance, athletes could benefit from a customized grip ensuring stable hold and the best force transmission from the arm to the tennis ball. Smart AM could fabricate unique rackets for athletes based on their current physical condition, the type of pitch, as well as temperature and altitude. With smart sensors, AM could even create new rackets in the middle of a long match, allowing the player to adapt his racket to the performance of his opponent. Golfers too could benefit from customized golf clubs. Based on collected data of an individual athlete's swing, a golf club could be customized with the right dimensions and weight balance to ensure a precise and powerful swing. Further, in luging, athletes could benefit from a customized sled ensuring a comfortable, stable and aerodynamic position while racing. Another noteworthy example is customized prostheses for Paralympics athletes. These examples—some of which are already reality to a certain extent—show that athletes from various sport disciplines benefit from customized sport equipment. To develop and construct the customized equipment requires solid data collection via smart sensors and smart AI applications; to produce the customized equipment requires AM.

3.4 Smart AM for Commercial Sport Applications

With smart AM not only professional athletes will benefit, but also the commercial sports industry. Smart AM solutions could create future concepts for retail stores enabling new business models. Instead of selling in-stock standard sports equipment, a future store concept could look entirely different: customers could enter the store and visit experience rooms that are dedicated to a particular sports discipline like tennis or golf. In these experience rooms, the customer could use specific items like a tennis racket or golf club and his data collected via cameras, sensors in the equipment, or other devices. After a short time, an AI algorithm creates fully customized gear for the customer as a CAD model, which can be then produced via AM. This new concept could establish new business models for sports retailers:

- First, sport retailers could offer fully customized equipment produced in-store. This would allow retailers to reduce stock levels and to improve the customer experience.
- Or, customers buy only the CAD models in store and print the customized equipment at home.
- A store could also offer a subscription model, whereby a customer pays a monthly subscription fee to update his sport equipment. This business model would address two important factors: On the one hand, since athletes' needs constantly change (e.g., due to performance improvement), they could continuously adapt their equipment. On the other hand, the store could introduce a circular economy model, where old equipment is returned, recycled, and used again as raw material for the AM machines.

Thinking of brand management and customer experience, these new store concepts could offer a real adventure for customers as they become more and more interactive. We already see the trend toward flagship stores with different experience areas today; the question is just when the actual business model and production concept will adapt. But customer experience could also be impacted in other ways. With 3D printers at home, for instance, spectators could buy a 3D model of their favorite football player right after he scores an important goal. The clubs themselves could sell a digital avatar and fans could print the memorable moment instantly. Similarly, digital gaming items could be a new business model for game console manufacturers like Sony or Microsoft. Gamers can advance in their favorite title and win prizes that can be printed at home. Some of them might even be attached to the controller in order to offer a new gaming experience at different levels of a game.

Thus far, we have focused on relatively small items, such as sports equipment or gadgets, but bigger applications could also become part of our future reality. Construction 3D printing has already been established and develops quickly (Houses et al. 2020). New pop-up stores, temporary experience studios for sports mega events, and even new structures for sports venues might be possible in the future. Though, to what extend the sports industry can and will benefit from these possibilities remains to be seen.

4 Opportunities and Challenges for Additive Manufacturing in Sports

When thinking about the future of AM in sports, one thing is obvious: It is not a question of if, but rather to what extent the technology will impact the industry. The sheer advantage of being able to fabricate products directly from a digital model will surely outperform the traditional manufacturing process (design, prototype, tool, produce) in many cases. Less time from idea to product will become increasingly important in tomorrow's world.

Today, only the limits of imagination form the boundaries or possibilities with AM. In the previous section, we discussed several opportunities of Smart AM based on current thought constructs. But technology will further evolve. We offer a potential timeline of AM in sports below:

- **Five years from now in 2025**: 4D printing has emerged, adding the dimension of time to products; thereby allowing objects to alter their shape and structure over time or based on environmental factors.[14]
- **Ten years from now in 2030**: Next to smart AM, additively manufactured sports nutrition has also entered the mass market. Bioprinting has advanced quickly and helps us not only in terms of injury healing but also in terms of optimized and environmentally friendly nutrition.
- **15 years from now in 2035**: Nanoscale AM has stepped out of its infancy (Ahn et al. 2015;[15]) The ability to print literally anything on a small scale has allowed us to produce smarter devices and include more intelligence in all sorts of sports equipment.

[14] https://www.3dnatives.com/en/4d-printing-disrupting-current-manufacturing-techniques-230920194/
[15] https://nanoss.de/de/nano3dsense-der-erste-3d-drucker-in-konkurrenzloser-nanometer-praezision/

- **20 years from now in 2040**: Nanoscale AM has enabled the production of smaller sensors and actors that work within the human body. Athletes can inject or implant nanobots that generate a totally new world of data and currently unimaginable ways of enhancing human performance have emerged.

No matter how abstruse some of these developments might sound, technological possibilities in 2050 will definitely exceed the most futuristic ideas of today. Therefore, the question to be asked is how to pave the way for further AM-related innovation in sports. To structure this discussion, it appears appropriate to take three different perspectives: design, production, and regulation.

- The first view on **design** reveals that the biggest challenge—but also opportunity—is usability. Both scanning and 3D modeling technologies need to become accessible and manageable for everyone. Today, it still requires a lot of effort and resources to generate a high-quality 3D model of body parts, for instance. Similarly, the digital post-processing requires specialized know-how and computing power. Thus, hardware and software allowing for "do-it-yourself" scanning and modeling could disrupt the market. Platforms like Thingiverse, MyMiniFactory, CG Trader, PinShape, YouMagine, and GrabCAD already offer (free) marketplaces for 3D models.[16] Customers can easily buy shapes and literally print them at home. However, the digital design process must become more intuitive and usable for a wider range of customers. Particularly with regards to the sports industry, dedicated platforms will gain importance. The future will determine whether established sports equipment manufactures will occupy this field or if leading AM companies will be the first to move. Likewise, it might be possible that tech giants or startups will challenge the sports industry incumbents by offering smart scanning devices, modeling software, and trading platforms.
- The second angle on **production** shows that the actual AM process has room for improvement. This holds true with respect to quality, cost, and time. While product quality from highly sophisticated AM machines is already at a solid level, most of the parts from smaller and cheaper 3D printers still require a reasonable amount of post-processing. It is only a matter of time, however, until mass-market AM equipment will also be able to produce highly finished items. Still, it will be interesting to observe whether shared or owned business models are going to succeed. Shared models would be based on centralized production facilities that fabricate AM products at a very large scale. Similarly, a more decentralized structure is imaginable, where each city or district has its own AM hub. These hubs could then be used by retailers and customers to order their customized products. This scenario would decrease logistical efforts and contribute to a more environmentally friendly production process. The most decentralized future scenario might occur if literally every household owns a private 3D printer. While this sounds unrealistic today, it might well become

[16]https://all3dp.com/2/best-thingiverse-alternatives/

reality in the future. Local AM machines that allow customers to print their products at home would require a significant advancement of current technology as well as a dip in cost and required manufacturing time. Printers would need to be able to combine different materials, add colors, and recycle non-used materials. Even if this seems futuristic, sports companies need to consider such scenarios as they would allow for entirely new business models and value chains. Eventually, it will be the innovators who will shape the sports equipment business of the future.

- Finally, **regulations** regarding technology will play a vital role for the sports industry. This holds true not only for AM, but for all kinds of technologies that will impact sports competitions. The discussion around *technology doping* has been ongoing for quite a while; there are two particularly prominent examples: the Speedo LZR Racer swim suit and the Nike Vaporfly 4% running shoe.[17] While the one-piece swim suit from Speedo helped athletes to break a series of world records through improved buoyancy and hydrodynamics, the Nike Vaporfly 4% even has the anticipated athletes' performance improvement of four percent in its name. With ultra-lightweight materials and a carbon-fiber plate in the sole, Nike wanted to help the two long-distance runners Eliud Kipchoge and Abraham Kiptum break the world record for marathon and half-marathon, respectively. Recently, Kipchoge went supersonic, running the marathon distance in less than 2 h (1:59:40) with the new Nike Vaporfly NEXT%.[18] Now the question remains if this is how elite sports should look. The International Swimming Federation (FINA) banned the Speedo LZR Racer ten years ago, thereby starting to establish boundaries for technology doping.[19] Similarly, World Athletics, the international governing body for the sports of athletics, announced new regulations for running shoes to keep technology doping in check.[20] However, technology will advance; and AM will play a vital role in creating new, customized, and performance-optimized equipment. Maybe, we will see a split in sports competitions—with traditional and tech-enabled contests. Similar to most of today's motorsports events, it might not only be a showdown of athletes, but a competition between athletes and their respective equipment. For spectators, this could become even more interesting and interactive as equipment could be manipulated during the competition. As mentioned, nanoscale 3D printing could allow for remote control of parts of the equipment or even allow athletes to use nanobots to drive performance to the limits. We may or may not like this vision, but technology–including AM—will

[17] https://www.forbes.com/sites/enriquedans/2020/02/06/nike-vaporfly-4-innovation-or-techdoping/#116f0f665919

[18] https://news.nike.com/news/eliud-kipchoge-1-59-attempt-kit-nike-zoom-marathon-shoe

[19] http://www.fina.org/content/fina-approved-swimwear

[20] https://www.theguardian.com/sport/2020/feb/06/world-athletics-foot-down-nike-running-shoe-regulations

make all this possible in the future. Whether or not it will become part of our traditional sports or create new types of sports remains to be seen. But without doubt, regulators will have to deal with these technology advancements; pure rejection, or abandonment of technology, will not be the answer—at least not in the long run.

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The Current State and Future of Regenerative Sports Medicine

Dietmar W. Hutmacher

Abstract

Regular engagement in sports not only produces many health benefits, but also exposes participants to increased injury risk. Hutmacher offers an overview of the progression of currently available regenerative treatment concepts and a summary of the different modalities of platelet-rich plasma treatments, bone marrow aspirate concentrate and precursor/stem cells, adipose-derived stem cells, and amniotic membrane products. General principles in the application of these treatment concepts are discussed. Finally, Hutmacher offers a critical, though visionary, view on how regenerative sports medicine technologies may lead to new treatment concepts and increasing engagement of both sports' injury patients and physicians.

1 Introduction

Sport, in the form of moderate physical activity or extensive workouts, is advised for young and old. They offer numerous health rewards to a wide range of the global community—from sportspersons performing at the highest level to folks of all age groups. The World Health Organization (WHO) published a report that states that energetic aerobic activity performed for more than two hours per week is correlated with reduced injury risks. Contrariwise, sport and exercise-induced ailments affect the described population, too. The risk of injury can have a simple single incidence due to acute trauma or a complex history that depends on several components. The causes can include the type of sport activity, the level of practice,

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and intrinsic factors like age, level of fitness, and genetic profile. From a health care perspective, regenerative sports medicine therapies may significantly improve patient quality of life, change the trajectories of diseases, and reduce the negative impact of chronic and degenerative conditions that currently affect a significant proportion of the amateur and professional sports population.

From an economic perspective, effective regenerative medicine therapies that provide curative options will greatly reduce healthcare costs. Hence, from a health economic and a personal perspective, the central objective of regenerative sports therapy should be to arrest or drive backwards the progression of injury and/or tissue degeneration. Early in the degeneration process, the main treatment aim is to recover the injured and/or traumatized tissue. At later stages of tissue dysfunction, the aim is to regenerate functional tissue substance, halt or heal acute or former scarring and injuries, and ensure athletes' improved body function. Cell therapy treatment during disease progression needs complementary regenerative approaches to halt injury and/or fatigue evolution, as well as to heal diagnosed tissue breakdown during exercise and/or sports competitions. Conventional therapeutic concepts, including rehabilitation and surgery, are rooted in patients' demands and personal requirements, i.e. the time of sport and exercise, performance limitations, and concomitant pathology. In contrast, regenerative treatments aim to provide new tissue with mechanical and physical properties indistinguishable from the original. This translates to absence of relapse after an athletic injury, a potential decrease in overuse injuries, and avoidance of several issues related to eminent changes in lifestyle.

The main regenerative technologies currently being investigated in the context of sports injuries are cell therapies and specific blood derivatives. From a molecular and cell biology point of view, there is variation in concentration and physiological balance of healing and/or anti-inflammatory factors. The use of human placenta-derived products is also capturing attention. In the context of musculoskeletal injuries, these products are often referenced as Orthobiologics. In general, musculoskeletal tissues have very good regeneration capacity under moderate exercise regimes. Yet, workouts that push to the physiological limits reveal the insufficiency of endogenous cells to drive regeneration and a compromised vascularity leads to chronic fatigue and/or severe injuries. Thus, the initial goal of cell therapies was to transplant living cells to engraft the tissue and generate high-quality extracellular matrix (ECM). The quality of the cells and the regenerated/repaired ECM is of major significance in sport and exercise. Ideally the ECM should confer flexibility and the ability to sustain high tensile and compression loads, thereby allowing the patient to get back to exercise and workouts without the risk of reinjury.

More recently, adult stem cell treatment concepts and applications in sports medicine have been used more often to deal with injuries and recovery. The promise of so-called "biologics" has motivated sports medicine professionals and is exciting to not only the physician but to the public and media as well. Biological augmentation can be defined as the science of using autologous stem cells and growth factors to enhance our own body's ability to repair and/or regenerate.

Several regenerative medicine rooted treatment concepts have been translated into modern sports medicine in recent years. This movement is rooted in a plethora of international studies and published research protocols supported by a catalogue of books for health professionals on the efficacy and efficiency of cell therapy, tissue engineering regenerative medicine (TE&RM), cell reprogramming, and genetic therapy (Administrator 2018). These new therapeutic lines can often be synergistically combined in strict compliance with the fundamental criteria of translational research and evidence-based medicine that encompass fundamental and applied research, clinical translation, and ultimately commercialization. One might argue that we are now standing at a crossroads, with one path leading to physical therapy-induced regeneration and the other to the realm of tissue engineering & regenerative medicine (TE&RM). This chapter explores the state of the art and future perspectives of RM on sports and exercise-induced injuries (Borg-Stein et al. 2018).

We envision the merging of advances in cell therapy, regenerative medicine, 3D printing, and biotechnology in the next decade. And, we present a case study of how the coming together of 3D printing and scaffold-guided tissue regeneration might impact professional athlete rehabilitation for articular knee injuries and improve lifestyle after a sport career.

2 Regenerative Medicine

Regenerative medicine is an interdisciplinary field and has evolved as an overarching term encompassing several well-established areas such as bioengineering, biomaterials science, genetic engineering, stem cell therapy, and biotechnology. As scientific researchers working in the field, one may define regenerative medicine as the application of scientific principles to repair, restore, supplement, or replace the natural function of a biological system (Dehghani and Rodeo 2019). The definition by the Medical Research Council (MRC) is, "regenerative medicine is an interdisciplinary approach that seeks to repair or replace damaged or diseased human cells or tissues to restore normal function" (MRC, 2017).

Acute and enduring exercise might result in major challenges to whole-body homeostasis provoking widespread distress in numerous cells, tissues, and organs that are caused by or are a response to the increased metabolic activity. To address this issue, multiple integrated, and often redundant, molecular and cell biological answers operate to counter the homeostatic burdens generated by exercise-induced increases in muscle energy and oxygen demand and/or overload on fascia, tendons, ligaments, cartilage, and even bone. The application of other fields such as biomechanics, biotechnology, biomaterials, and TE&RM to exercise biology has provided greater understanding of the multiplicity and complexity of cellular networks involved in exercise responses. Recent discoveries offer perspectives on the mechanisms by which the muscle "communicates" with other organs and mediates the beneficial effects of exercise on health and performance.

For more than 20 years, it was postulated that the muscle and other organs communicate via organized cell signaling pathways. This hypothesis was proven recently by studying in detail contracting muscles and the effect on organs. However, in many cases, normal responses and adaptations to both acute exercise and enduring exercise can be seen when one or more key pathways are absent, blocked with drugs, or otherwise controlled. This biological redundancy indicates that perhaps the only enforced reaction to exercise is the defense of homeostasis itself. Clearly, a big challenge for exercise researchers in the years to come will be to connect distinct signaling cascades to defined metabolic responses and specific changes in gene and protein expression in skeletal muscle that occur during and/or after individual workouts or sports games. This will be challenging because many of these pathways are not linear and they rather constitute a complex network with a high degree of crosstalk, feedback regulation, and transient activation. The many "omics" technology platforms and the utilization of validated computational and systems biology protocols to questions and hypotheses posed in the emerging field exercise biology are poised to accelerate in time to become sports therapy innovation.

It is well known that participation in sports and exercise modifies the human physiological state. Physical stress response during or after a training session or a sport challenge alters the equilibrium of the biochemical internal environment, which means that it affects the rate of production or synthesis and the kinetics of the metabolites that are related to exercise intensity and/or muscle damage. Sportomics is defined as "the application of metabolomics in sports to investigate the metabolic effects of physical exercise on individuals," whether they are professional athletes or amateurs. Metabolomics is one of the "omics" sciences that provide a picture of the metabolic state of a person in physiological or pathological conditions. This is achieved through the analysis of metabolites present in a biological fluid, such as saliva, blood, feces, and urine. The sportomics approach may be complementary to the current methods of studying and monitoring and athlete's state of fatigue and physical performance. It could also be used to predict future injury susceptibility.

3 Cell Therapy

The key regenerative medicine concepts currently being investigated in the context of sports fatigue and injuries are cell therapies including allogenic, autologous, and blood derivatives generated from the patients' blood or donors. All blood-derived products require knowledge of the best concentration and physiological balance of therapeutic and/or anti-inflammatory factors for each treatment. The use of placenta products is also capturing attention. In the context of musculoskeletal injuries, these products are often referenced as Orthobiologics. As the topic of the emerging regenerative technologies is already broad, this section will focus on cell therapies and blood-derived formulations (Borg-Stein et al. 2018).

To meet the clear demand presented by sports-related injuries, biological products are used mainly to accelerate healing and restore function. Advances in this field are based on the scientific understanding of molecular and cell biology in tissue healing processes. Foreign stem cells can be implanted to take the role of resident cells. Alternatively, molecular pools combined in a physiological balance (blood-derived products or placenta products) can stimulate new blood vessel growth (angiogenesis), host stem cell migration, and tissue anabolism, thereby turning on regeneration mechanisms at the injured tissue location. But present research has yet to activate the required body/tissue response in a sequential and spatial manner to make current treatment concepts more effective. Many sports medicine professionals and clinicians administer many of these therapies with unspecific goals and hence the results (Hutmacher et al. 2015).

Hard workouts and even moderate physical activity impact whole-body homeostasis. A large number of acute and adaptive responses take place at the cellular, tissue, and systemic organ levels that function to reduce tissue fatigue and injury. During localized injury, mesenchymal precursor cells (MPCs) are released from the perivascular location, become activated by secreting bioactive molecules, and regulate the local immune response—establishing first a proinflammatory followed by creating a so-called pro-regenerative niche. However, today all the work conducted on adult stem cells (ASCs) is mainly focused on cells derived from bone marrow and adipose tissue without considering that not only these two sources, but also the originate from other sources such as blood, the umbilical cord, and placental stroma contain MSC precursors that can be easily separated and extracted (Johal et al. 2019).

4 Bone Marrow Aspirate

As medical knowledge and technological innovation have progressed, the healthcare community has continued to explore the field of regenerative medicine and the many therapeutic interventions that it has to offer. Within the realm of sports medicine, the therapeutic application of bone marrow aspirate (BMA) has been contemplated ever since it was discovered that this tissue stored cells with chondrogenic and osteogenic capacity.

BMA therapy is a low-risk, non-invasive treatment that can be used to treat sports injury conditions such as cartilage, bone, tendon, and ligament tears and lacerations anywhere in the body.

Bone marrow-derived stem cells (BMSCs) for regenerative sports medicine procedures can be processed and manufactured in two different protocols, cell culture or cell isolation, without further manipulation. MSCs derived from BMA can differentiate into many different types of tissues including muscle, bone, cartilage, and tendon. However, an additional mechanism by which MPCs stimulate tissue repair is through the rendering of growth factors and cytokines. This mechanism is defined as "paracrine action." MPCs promote various growth and other factors to locally recruit neighboring cells to stimulate tissue repair (see Fig. 1).

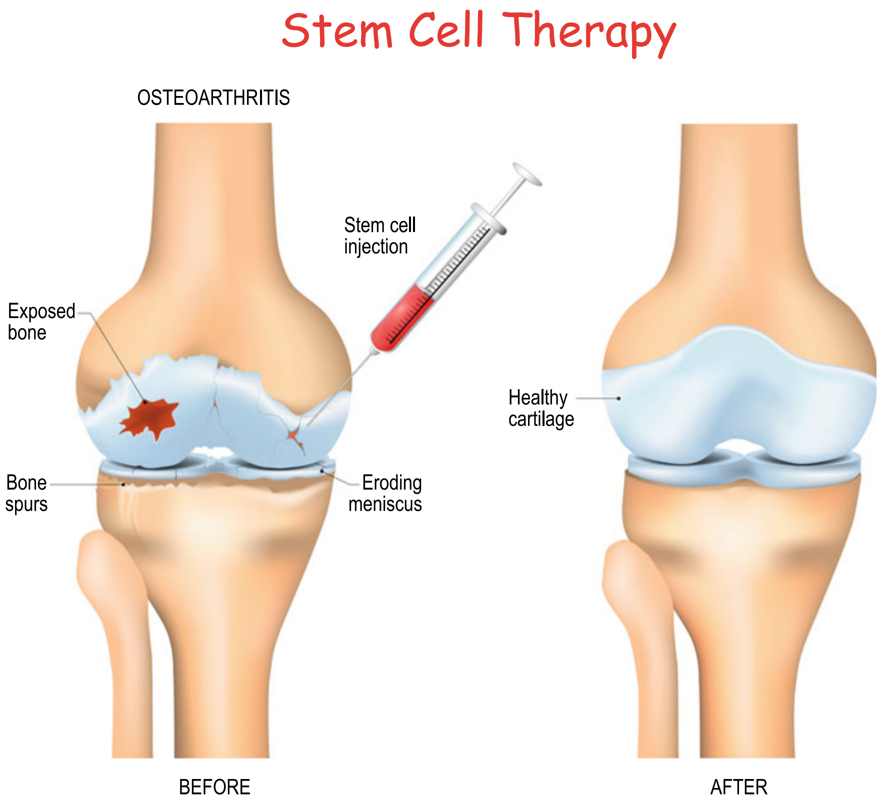

Fig. 1 Cell therapy concept for cartilage repair after trauma sports injury or tissue degeneration from exercise

Non-cultured cells are used directly after concentrating the cells from the initial aspirate by centrifugation at the point of care. Currently, noncultured, naturally occurring cell concentrates are permitted for patient use in most of the countries around the world, whereas cultured cells are often prohibited for this use by regulatory authorities such as Food and Drug Administration (FDA), etc. Clinics in jurisdictions with less regulatory oversight, market treatments with expansion of BMAC. The safety profile of cell therapy treatments should not be forgotten. Safety matters incorporate maintenance of sterility of in vitro culture for expanded cells, quality control and clearance of cytokines used for culture expansion, and genetic stability of culture expanded cells (Liu et al. 2019).

Despite widespread application of Orthobiologics by sports medicine professionals to treat sports actuate trauma, fatigue, and more chronic pathologies, there are still several areas of disagreement among the different stakeholders in RSM. Orthobiologics products often use different tissue sources and therefore have varying make-ups and production techniques. It is, therefore, often difficult to compare outcome studies and to evaluate the efficacy of these treatment concepts and cell-derived products based on evidence-based principles. Hence, there is a need to standardize equipment, formulation protocols, and biological elements of Orthobiologics.

5 Platelet Rich Plasma

Platelet Rich Plasma (PRP) injection has been used in sports medicine for decades to assist in the healing process of wounds and in certain sports surgery operations. PRP consists of a normally occurring concentrate of platelets made from centrifuging whole blood to increase platelet concentration and removing other cellular components. For efficacy, the platelet concentration must be higher than baseline. The proposed mechanism for PRPI as a therapeutic is that PRP initiates the body's own repair processes, modulates inflammation, delivers growth factors, and attracts and activates mesenchymal stem cells, which promote a healing environment and reduces pain (Scully and Matsakas 2019).

The scientific literature provides evidence that platelets have an important role in tissue and organ homeostasis. Platelets produce and deliver via paracrine effects a large number and volume of growth factors (GF)s on a daily basis just to maintain tissue and organ homeostasis. GFs are also very important to orchestrate wound healing and regenerative processes. It is supposed that these growth factors are at high concentrations in the PRP. In addition to growth factors, platelets release certain substances that are also important for muscle recovery after exercise or sports injuries. An advantage of PRP, with respect to using single recombinant human growth factor delivery, is the release of a growth factor cocktail and cell migration, proliferation, and differentiation factors due to platelet activation.

In the twenty-first century, many physicians decide to approach this new therapeutic field to boost their practice and have little or no knowledge at all of the science behind it. Many of these tools are "push button machines" supported by economical and "ready-to-use" kits. What most of these doctors know about PRP is where to buy the tools and how to open the kit and press the "on" button. Many of the tool manufacturers have misled physicians by selling them the PRP as a stem cell procedure, consequently increasing the marketing hype and worsening consumer confusion (Jones et al. 2018).

Unfortunately, once a clinician makes an investment into an automated machine that generates a specific PRP type, it is all he or she uses in practice. That there are several formulations and compositions of PRP are not taken into consideration likely due to a lack of knowledge of the relevant literature. Almost every company offers a different set of technical features, concentrations of GF, and therapeutic actions often not linked to validated sports injuries or exercise recovery protocols. Unfortunately, most doctors are still using red PRP, which is cheaper and easier to obtain, even with the fancy artisanal techniques often employed. This oversupply of white cells stimulates a huge cytokine activation resulting in additional inflammatory response. Interfering inadequately with the regenerative action often voids advantages and benefits and feeds the false idea that “PRP often fail.” For example, yellow PRP, lower concentration amber PRP, high-concentration amber PRP, plasma rich in GF, and platelet lysate (PL) deliver a greater concentration of specific and unspecific GF–from 20 to 45% more—and cause fewer side effects and risks of complications.

PRP seems to offer an immediate release of the growth factors and an important anti-inflammatory action and is, therefore, particularly suitable to be added whenever a high concentration of regenerative components in a very small volume is required. For example, small PRP volumes are required when treating hip and shoulder joints, muscle and ligaments to bone attachments, and vocal cords. At present, only a few automated and very expensive machines can produce this type of PRP, so its clinical use remains less common. If the required clinical data are generated in the future via evidence-based studies, this PRP cocktail could be a very powerful tool in regenerative sports medicine (Hutmacher et al. 2015; Jones et al. 2018).

In summary, in the face of the exponential growth of RM treatment agents in sports trauma and pathologies, there are still several areas of controversy and a lack of documentation in the medical literature. There is still no consensus on the optimal protocol for preparing PRP and BMAC. Thus, products termed “PRP” and “BMAC” generally have multiple compositions and differ greatly in how they are produced. It is, therefore, difficult to compare outcome studies and to evaluate the efficacy of these agents. There is a need to standardize preparation protocols and composition of both PRP and BMAC. Unfortunately, few physicians possess the scientific knowledge and technical expertise to understand and master regenerative procedures to safely and effectively approach this very rewarding but challenging discipline. Hence, universities and especially medical faculties should consider offering Master’s level courses in regenerative sports medicine to educate the next generation of physicians in this very important field (Scully and Matsakas 2019; Chou et al. 2020) (Fig. 2).

6 Can Young Blood Infusions Stimulate Regeneration?

An injection of “new blood” is an idiom often used as an allegory for the revitalizing impression of fresh minds on the management in what is defined as old school company. But new research suggests it may also be valid in a literal sense. In a development that calls to mind old movies and sagas of vampire lore, young blood appears to, in fact, rejuvenate old brains. In a 2014 study at Stanford University led by neuroscientist Tony Wyss-Coray, infusions of blood from young mice reversed cognitive and neurological impairments seen in old ones. The methodology called “parabiosis,” is based on the exchange of the blood of two living organisms. For example, two mice were sutured together in such a way that they shared a circulatory blood system. Researchers found that when old mice were

Fig. 2 a and b: **a** Graphical illustration of current PRP injection sites for sports injury treatments. **b** PRP injection into knee joint

surgically joined to their youthful counterparts, they showed changes in gene activity in the hippocampus, increased neural connections, and enhanced “synaptic plasticity”—a mechanism believed to underlie learning and memory in which the strength of neural connections change in response to experience. They also gave old mice infusions of young blood plasma, the liquid component of blood containing proteins and hormones but no cells, which significantly improved their performance in learning and memory tests. These findings may have profound implications if they can be replicated in humans. Several researchers have advised the public that the procedure is dangerous for certain patients—including those whose original science inspired it. Irina Conboy, a professor of Bioengineering at the University of California at Berkeley who studies young blood transfusions in mice, argues that the treatments can be dangerous because they don’t fall under professional oversight. From a FDA perspective, “blood as a drug” is not a regulated product.

In 2017, a start-up, Ambrosia, enrolled people in a clinical trial designed to find out what happens when the veins of adults are filled with blood from younger people. Of notice, the results of this particular study have not been published. The two-day experiment involved patients receiving 1.5 L of plasma from a pool of donors aged 16 to 25. Before and after the infusions, participants’ blood was tested for a small number of biomarkers. These measurable biological substances and processes were thought to provide a snapshot of health and disease. The science on whether infusions of young blood plasma could help fight aging remains blurred at best. Furthermore, if this treatment shows clinical efficacy it most likely can be only applied to nonprofessional athletes as it would violate the current anti-doping rules.

7 Exosome Therapy

Until recently, exosomes were regarded as unimportant or even cellular waste. Now, it has been recognized by the wider scientific and clinical community that exosomes have many important cellular functions. Exosomes are cell-derived vesicles that contain endogenous proteins and nucleic acids; delivery of these molecules to exosome-recipient cells causes biological effects. Exosome vehicles (EVs) derived from mesenchymal stem cells (MSCs) and dendritic cells have therapeutic potential and may be efficient agents to help to repair exercise fatigue and sports injuries.

After being delivered to the sports injury site, exosomes can act upon target cells in the vicinity of the parent cells in a paracrine manner; they can also enter biological liquids such as plasma and joint fluids to be delivered to target cells far from the secreting cells, similar to an endocrine process. When exosomes are absorbed by specific target cells, the exosome contents orchestrate a large number of signal pathways. Today, exosomes have been predominately studied in their roles in cancer progression and immunoregulation. Also, biomolecules in exosome vesicles (EV) have been most recently applied as biomarkers for disease diagnosis, prognosis, and even injury conditions since their levels or contents might change

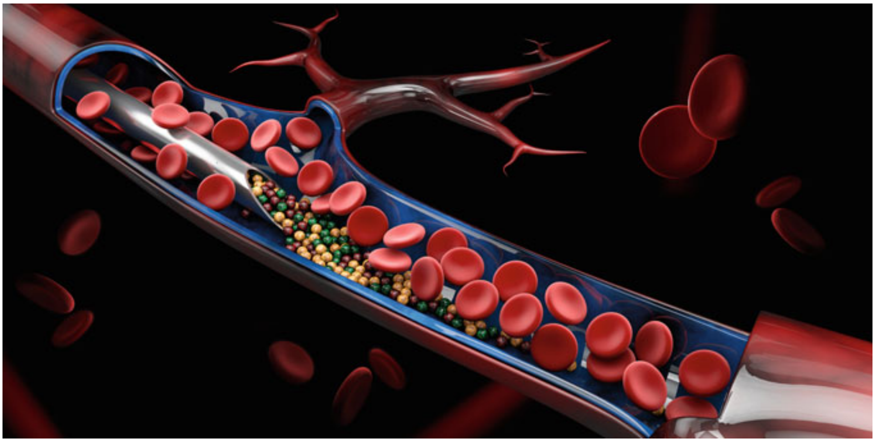

Fig. 3 Regenerative potential of injection of exosomes has been reported in some sports patients with OA. It is reasonable to believe that more regenerative potential of exosomes will be discovered in the future

following the occurrence of endurance fatigue or sports trauma injuries. For example, most recent studies showed that exosomes are the main bioactive vesicles responsible for the paracrine effects of MSCs; they regulate many physiological and pathological processes by affecting the survival, proliferation, migration, and gene expression of recipient cells and by reprogramming targeted cell behaviors (see Fig. 3).

From this background, it could be possible to develop a cell-free therapy making use of biomolecules that have a paracrine effect like exosomes. This treatment would stimulate tissue repair and regeneration and reduce a number of risks and patient safety concerns associated with direct stem cell transplantation. Numerous preclinical studies have confirmed that MSC exosomes play a key role in tissue regeneration and repair, particularly in cutaneous wound healing. MSC exosomes participate in each phase of the cutaneous wound healing processes by delivering various molecules. However, their full functions still remain unclear. It is believed that MSC exosome-mediated therapy could play an essential role in providing cutaneous regeneration and/or repair after injury.

Tendons and ligaments next to muscles are highly prone to injury during sports and other rigorous physical activities. Tendinopathy is a common chronic musculoskeletal system disorder affecting mainly the professional, but also the amateur sports population worldwide. This type of tissue destruction is very painful and has a significant detrimental effect on the patient's life quality. Many treatments for tendinopathy have been applied in clinical practice to restore tendon function and maintain the patient's quality of life including nonsteroid anti-inflammation drug intake, administration of steroid injections, and physical therapies. However, their effects are largely limited to pain control and scar-like repair; most often, they do not lead to true tendon regeneration. Most recent reports have shown that exosomes from mesenchymal stem cells have a potential regenerative medicine application for tendinopathy. Tendon precursor cells are a kind of MSCs, however, the effects of exosomes from this cell type on tendinopathy are unclear. Nonsurgical stem cell-based options for treating orthopedic injuries have not been approved by the FDA; they are expensive but are available in clinics around the world (outside of the US). Because of EVs nanosize, high biocompatibility, biodegradability, and ability to incorporate and deliver functional molecules to target cells, EVs as targeted delivery systems for molecular therapy in skeletal sports disorders is an attractive idea.

For example, let's look at a professional sports patient case. NFL player Jimmy Graham had stem cells harvested from his bone marrow and injected into his knee to minimal benefit. Then, he heard about a treatment in Europe that deploys exosomes generated from stem-cell secretions, instead of the stem cells themselves. For the treatment, Graham had a fat graft taken from his abdomen in the United States and shipped to a clinic in London. There, the stem cells were isolated and placed in an oxygen-deprived environment to induce them to secrete EVs that stimulate tissue repair and regeneration. The EVs dose needed for having an effect after the injection required several weeks of labor and costly cell culture. Finally, the EVs were infused into Graham's body intravenously in a London clinic rather than being injected into the injury (as most stem-cell treatments are administered). Graham stated that his knee has been pain-free since. Also, his chronically sore back improved tremendously, and a medical scan revealed that a slight tear in his other patella had healed. However, as this is a single case and not an evidence-based clinical trial, physicians and scientists warned of the considerable risks in trying these unproven therapies and the unreliability of single-case results. They also emphasized that stem cells and EVs need to be studied in more depth under FDA regulated standards to prove safety and efficacy.

One argument for the safety of EVs and stem cells is that they are taken from the patient's body so there is a low risk of rejection. Another positive aspect is that with an intravenous infusion, in this particular case with EVs, there is no risk of causing further injury from injections into the injury site. For these reasons, exosomes have a high potential for clinical administration. But, determining suitable cell sources should not be without condition. For example, the cell source should be efficient and suitable for regeneration, available in large quantities, and isolation and purification should be possible on a large scale. Moreover, because exosomes contain different molecules like proteins, mRNAs, and miRNA that affect the physiological function, special storage conditions are required. If exosomes are packaged at optimal biological dosages, they can be used in clinical applications and, hopefully, provide a suitable alternative to common treatments. The wider scientific and clinical community, however, remains unconvinced: "…without scientific study and a better understanding of the long-term risks of these types of treatments, they need to be used very cautiously." Randomized clinical trials are currently underway, and I am eagerly awaiting the results and outcomes.

8 Cartilage Tissue Engineering

The highest number of sports injuries seen by sports medicine professionals are chondral and osteochondral defects (OCD) in the knee and ankle. In addition, there is high incidence of overuse conditions, i.e., injuries produced along a continuum, without identification of any punctual event responsible for the condition. These sports injuries are the result of an imbalance caused by continuous mechanical load-induced tissue fatigue and ultimately damage and the inability of cartilage to remodel and repair itself. Unfortunately, most overuse injuries have little capacity for reversibility once a threshold of tissue degeneration is surpassed.

The affected body region is often sport specific and particularly affects athletes competing at the highest levels. A systematic review of 11 studies revealed 36% (2.4–75%) prevalence of full-thickness focal chondral defects. The analysis included a total of 931 subjects, of whom 40% athletes were former players in the National Basketball Association (NBA) and the National Football League (NFL). The prevalence of secondary knee and hip osteoarthritis (OA) in former professional soccer players is 2–3 higher. Likewise, hip OA is more common in elite athletes competing in impact sports (i.e., soccer, handball, track and field, or hockey) than in those participating in high-level long-distance running.

Osteoarthritis (OA), the predominant cartilage disease, is characterized by a loss of cartilage, typically progressing from superficial cartilage fibrillation to complete erosion of the subchondral bone. OA causes pain and debilitation in more than two million sports patients in the United States with comparable incidence in Europe and Asia. Furthermore, the numbers affected by this age-associated disease are projected to increase dramatically with the aging of the population. The most common treatment for advanced OA is joint replacement surgery, in which not only the damaged hip or knee joint tissues but also healthy bone is surgically cut off and replaced with so-called artificial joint replacements. This operation is performed in millions of patients around the world every year; more than 90% of the patients see an immediate reduction of pain and an increase in daily mobility and potential to exercise. However, implants fail over time and require revision surgeries, which are highly invasive, complicated, and costly. Thus, alternative treatment strategies are being investigated, including cartilage tissue engineering, where biomaterials and cells are combined to rebuilt dynamic tissues to repair and regenerate damaged articular cartilage. With the emergence of tissue engineering, the prospect of replacing the damaged cartilage with cartilaginous tissue constructs has been translated to the clinic.

9 Evidence-Based Medicine

Cellular therapies and cell-based assays are meant to revolutionize the diagnosis and treatment in sports medicine. This has generated excitement and hope among amateur and professional athletes and their physicians. However, despite the enormous progress and promise in the field of cell therapy development, several unresolved challenges continue to plague the field. There is a need to discover new things but not to generate false leads. Differentiating between promising discoveries and false leads has been a reoccurring issue in regenerative sports medicine over the last ten years.

Clinical diagnostics and therapies demand unprecedented rigor in characterization, control, documentation, and reproducibility. These demands defy the intrinsic variability and heterogeneity that is present in most biological systems. In some settings, reproducibility is already possible. In other settings, particularly in personalized medicine and cell therapies, we must learn to understand and use biological heterogeneity to our advantage. This involves first measuring heterogeneity, and then using that knowledge to become more selective in choosing what cells we include and exclude from cell products and cell assays. A critical challenge that limits translation of many technologies into effective therapies is the ability to define and measure critical quality attributes in the stem cell and progenitor populations. These attributes must be defined based on quantitative and standardized metrics. Only with this information can we then act, using appropriate tools, to rapidly identify and isolate desired cells or clones or to delete undesired cells/clones for use in clinical diagnostics and safe and effective clinical therapies.

10 Conclusions and Future Perspectives

The future of Orthobiologics in the treatment of sports medicine is exciting. Sports medicine physicians are in the early stage of understanding its clinical uses and application. To meet the clear demand of sports-related injuries, biological products are used with multiple aims, mainly to accelerate healing and restore function. Advances in this field are based on the scientific understanding of molecular and cell biology in tissue healing and activating repair mechanisms (see Figs. 3 and 4).

As of today, sports medicine applications for PRP show promise; but with so many products available, varying concentration levels, and variability in the application, clinical interpretation is difficult. With the heterogeneity in tendons and tendinopathies, defining protocols is important. There is some good data, but the results are not completely clear. Protocols need to be standardized. Identifying what works in the human environment is also needed. For example, future research must determine the correct platelet leukocyte count and the balance ratio between the two, as well as what plasma proteins are helpful in specific clinical settings. In the future, we may see second-generation PRP that will neutralize the negative or unwanted growth factors and enhance the positive growth factors. Maybe there will be a combination of PRP or other blood products added to a stem cell or some scaffold that will produce an improved and predictable clinical result. As we learn more, we can try to exclude unwanted growth factors and concentrate on the positive growth factors; perhaps we can even use blood sources other than platelets.

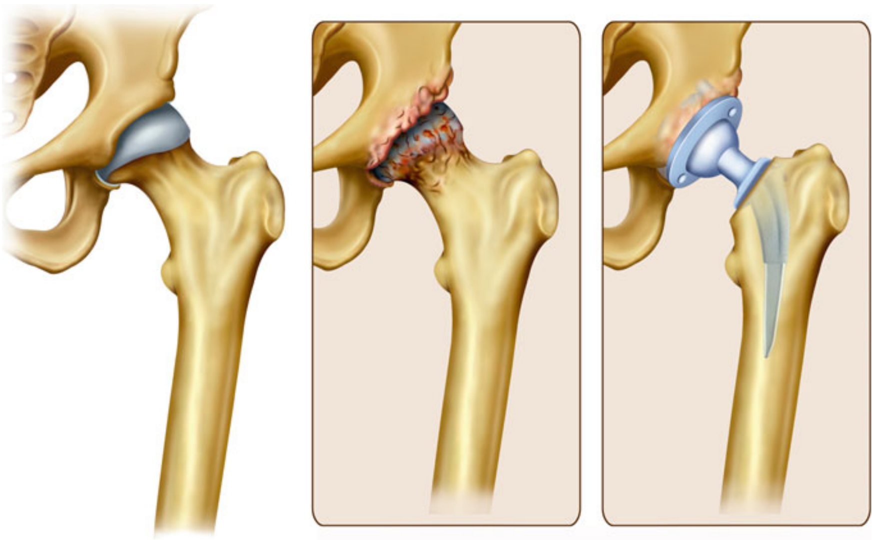

Fig. 4 Hip replacement surgery is commonly performed to treat hip conditions such as severe osteoarthritis. Globally, over two million total hip replacements are performed annually

There is currently low-level evidence to support the use of PRP for tendinopathies of the elbow and osteoarthritis of the knee. Additional studies appear to demonstrate efficacy in other tendons and ligaments. Although some reports have shown effectiveness, stringent medical evidence is lacking for the use of prolotherapy and stem cell therapy, in addition to PRP for muscle strain. More rigorous studies using these biological agents to treat such injuries could potentially change the way most sports injuries are managed. The true utility of regenerative medicine for sports injuries will become clearer as more high-quality research is published.

Future research in the field of regenerative sports medicine requires increasingly sophisticated approaches to understand which therapies can show efficacy and efficiency for athletes. The main regenerative technologies currently used in the clinic in the context of sports injuries are cell therapies, placenta products, and specific blood derivatives, mainly platelet-rich plasma. Research on PRP therapies points to a moderate effect on pain and functional recovery in tendinopathy and osteoarthritis. However, given the heterogeneity of products and patient variability, further controlled clinical trials are a condition sine qua non.

Local application of mesenchymal stem/stromal cell products is safe, but high-quality translational research is needed to shape effective clinical protocols able to exploit the capacity of cells to support tissue repair and alleviate the effects of tissue degeneration, either by engrafting the tissue or by paracrine actions. The hype created by media around mesenchymal stem/stromal cell therapies for sports trauma or overuse injuries needs to be supported by scientifically solid outcome data from good quality trials.

The sportomics approach may be complementary to the current methods of studying and monitoring athlete's state of fatigue and physical performance. It could also be used to predict future events, such as onset of illness, talent identification, and injury susceptibility. It would be possible for everyone to choose the best physical exercise or sport (particularly important during infancy and childhood) to preserve and improve the health status; and it would be possible to personalize nutrition based on an individual's metabolomic framework.

In closing, the regenerative sports medicine community needs to develop conditions for research and innovation characterized by creativity, agility, and openness. This requires setting thematic priorities and focusing effort on fields that show particular dynamism, have great potential for growth, and exhibit a high need for innovative solutions. At the same time, stakeholders should be consistent in developing true competency in technologies through training and further education; thereby, they can ensure the viability of the sports community on a long-term and sustainable basis. Particular focus should be given to new forms of interdisciplinary ideation and the acquisition and sharing of knowledge, which make it possible to reshape and open up innovative treatment concepts for sports injuries and chronic fatigue. Strengthening knowledge transfer and networking is important so that all stakeholders involved in innovation in science, business, and society can participate in new constellations that overcome ingrained mindsets and disciplinary silos.

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Big Data, Artificial Intelligence, and Quantum Computing in Sports

Benno Torgler

Abstract

This chapter examines the exciting possibilities promised for the sports environment by new technologies such as big data, AI, and quantum computing, discussed in turn. Together and separately, the technologies' capacity for more precise data collection and analysis can enhance sports-related decision-making and increase organization performance in many areas. Torgler also emphasizes technologies' limitations—and considerations like privacy and inefficiencies—by reflecting on the nature of sport. Finally, it explores the factors beyond technology that influence individual's deep involvement in and emotional attachment to sports and sports-related events.

How puzzling all these changes are! I'm never sure what I'm going to be, from one minute to another.

Lewis Carroll, *Alice's Adventures in Wonderland.*

I know that it is ninety feet from first base to second base, ninety feet from second base to third base, and that a baseball batted between those points is fair. I know that approximately 20 out of every 100 balls batted fair during the season are 'safe hits.' I know that of 1,284 ground balls batted during the season of 1909 in the American and National leagues (1,284 chosen at random) 138 got past the infielders. I know that infielders of the National League (pitchers not included) fielded 9,382 ground balls errorlessly during the season of 1909. But how many millionths of a watt constitutes the chances of a hit being safe I cannot figure out. The average speed of fifty ground balls hit in three games during which three of us held twentieth-of-a-second watches we calculated to be 100 feet in one and three twentieth seconds. We know that the third baseman plays ordinarily about 96 feet from the home plate, that the short stop playing 'middling deep' is about 130 feet from the batter, that the second baseman is about two feet closer, and the first baseman 90 feet when a runner is on first base and 102 when no one is on bases. Given the speed and direction of the ball and the

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> speed of the player, it is possible to figure to a millionth of a watt where his hands will meet the ball; but just as you start to write Q. E. U. the ball will take a bad bound. Given the average speed of the infielders, it would be possible to calculate beforehand approximately the number of base hits each team will make in a season—if the players were automatons.
>
> Fullerton (1910), *American Magazine*, p. 3.

> Turning to quantum mechanics, we know immediately that here we get only the ability, apparently, to predict probabilities. Might I say immediately, so that you know where I really intend to go, that we always have had (secret, secret, close the doors!) we always have had a great deal of difficulty in understanding the world view that quantum mechanics represents. At least I do, because I'm an old enough man that I haven't got to the point that this stuff is obvious to me. Okay, I still get nervous with it. And therefore, some of the younger students … you know how it always is, every new idea, it takes a generation or two until it becomes obvious that there's no real problem.
>
> Richard Feynman (1982), p. 471.

1 Introduction

Competitive sports and athletic games have evoked deep emotional involvement from old and young, rich and poor in both modern and ancient societies, with superior performances greeted by visceral reactions of excitement and awe. The 2018 FIFA World Cup, for example, attracted a combined individual viewership of 3.5 billion, equivalent to half the global population aged four and above,[1] and rarely do people enter disputes or embrace their loyalties in quite the way (or to the degree) as when sports is the topic of conversation (Weiss 1969). It is not surprising, then, that the sports environments have recently been penetrated by the new technologies of big data, artificial intelligence, and quantum computing, whose capacity for more precise data collection and analysis can enhance sports-related decision-making and increase organizational performance in many areas (Brynjolfsson et al. 2011). Just as political campaigns, governments, and businesses use big data from social media, census, and voter lists, and active outreach to get ahead of the curve and learn as much as possible about their constituents or customers (Weber et al. 2014), decision-makers in competitive environments like professional sports are naturally incentivized to use decision-enhancing tools and instruments that exploit the potential of advanced technologies.

As a result, the *analytical* way of winning outlined in Michael Lewis's 2003 *Moneyball* drew major attention, culminating in a film adaptation with Brad Pitt as Billy Beane, general manager of the Oakland Athletics baseball team, and Jonah Hill as Peter Brand, the young Yale economics graduate assistant full of new ideas about how to assess player value. In this inspiring David and Goliath story, rigorous statistical analysis replaced a slingshot as the secret weapon, one whose deadly

[1] https://www.fifa.com/worldcup/news/more-than-half-the-world-watched-record-breaking-2018-world-cup.

precision allowed the underdog to compete successfully with far better-funded rivals in major league baseball (MLB). Armed with this highly accurate instrument, the Oakland A's stayed ahead of the curve and reached the playoffs for four straight seasons in the early 2000s despite substantially smaller budgets than league "big boys" like the New York Yankees. In fact, during the 2002 season, the Oakland A's tied with the Tampa Bay Devil Rays for the lowest payroll in the league (about 40 million USD), while the New York Yankees benefited from a payroll more than three times that amount (140 million USD). Yet the A's won more games across the 2001 and 2002 seasons than the Yankees (205–198) despite being unlucky in the playoffs.

Strategically, selecting for undervalued baseball skills such as defensive capabilities is like opting for David's sling rather than Goliath's spear and armor. Hence, although the Oakland A's data strategy was specific, the story's appeal is universal: success in the face of overwhelming odds elicits feelings of greatness and beauty (Gladwell 2013), inspiring wide replication. Such narratives not only represent the clash between rich and poor or between strong and weak, but also that between traditionalists and sabermetrics, between intuition or gut feeling and statistics, and between the democratization of decision-making through data and authoritarian decision-making by specific decision-makers. This modern contest is in fact playing out well beyond the stadium as managerial decisions rely less on a leader's gut feelings and instincts and more on business intelligence systems whose analytic tools enable in-depth investigation of a broad array of data (Brynjolfsson et al. 2011).

At the same time, the collection and analysis of sports data are becoming increasingly dependent on newly developed sports information systems capable of fast and automatic evaluation of sports-specific parameter values (Novatchkov and Baca 2013a, b). For example, in the lead-up to the 2018 World Cup in Russia, "many teams boasted a scientist on board to crunch the numbers to understand the strengths and weaknesses of the opposition, including how the network of each team behaves" (du Sautoy 2019, p. 55). This chapter therefore takes a closer look at the key applications and implications of big data and AI in sports, as well as what to expect from sports application of quantum computing. It also addresses the limitations of such technologies by reflecting on the nature of sport.

2 Sports' Journey Through the Supercollider

2.1 Power of Sensoring Systems

The exponential growth in technological advances (Kurzweil 1999, 2012)—including wearable nonintrusive and noninvasive instruments for monitoring athletes' physiological processes—has opened up new ways of understanding human nature (Torgler 2019). The attraction of nonintrusive tools like surface electrodes is their potential to identify psychological or mental processes that are otherwise hard to measure. The rich continuous data they produce (e.g., second-by-second pictures; Pentland et al. 2009, p. 4) offer new ways of understanding human dynamics (Eagle and Pentland 2006) and the messiness of human interactions in and outside the sports arena. These multimodal tools, appropriately dubbed "social fMRI" (Aharony et al. 2011), enable trainers to put athletes through a type of social supercollider, harnessing 24-h measurements of real-time continuous biological data linked to behavior and environmental conditions via a combination of multiple data sources. By ensuring the proper observation of, or controls for, individual environmental and situational realities (Eagle and Greene 2014), such reality mining gives trainers access to a richer, more realistic portrait of athletes' physical and mental conditions, as well as their responses to, for example, training changes or contextual environmental factors like stress situations before, during, and after competition.

These digital footprints, now used intensively as exercise and training data in the field, can improve athletes' performance, long-term health status, and stress resistance, and even prolong their sports career (Passfield and Hopker 2017). Real-time analysis is achieved in elite sports via several applications of wearable technology (for an overview, see Page 2015). For example, adidas' elite *miCoach System* is an advanced physiological monitoring method used by Germany's team in preparation for its victory in the 2014 FIFA World Cup. The team also used it during training sessions in Brazil to monitor player performance, plan workouts, identify player fitness, and understand player movements in different positions.[2]

Nonetheless, although current research into biosensing focuses primarily on exercise-related physiology (see, e.g., Guan et al. 2019), new technologies can go beyond this aspect. For example, a group of MIT scholars (see Pentland 2008, 2014) developed a sociometer designed to quantify human social behavior in the context of social networks by focusing on social signals like body language, facial expression, voice tone, and speech measures such as energy, pitch, and speaking rate (Gatica-Perez et al. 2005). In particular, they targeted social interactions such as individual turn-taking (Choudhury and Pentland 2004) while also measuring stress via variation in prosodic emphasis (Pentland 2008). According to Pentland (2014), the sociometer can "accurately predict outcomes of dating situations, job interviews, and even salary negotiations" (p. xi) with sensors that extract information on both the users' behavior and their environment, including location, ambiance, and others involved in the conversation (for a discussion, see Torgler 2019). Stopczynski et al. (2014) even constructed a "smartphone brain scanner" built on open source software that provides real-time imaging of brain activities (low-density neuroimaging), using neuroheadsets with 16 electrodes placed on the scalp to produce 3D EEG imaging. Given the need to better understand the connection between the brain and sports performance, such mobile brain scanners may hold great potential for athletes, particularly if wearing them is nonintrusive.

[2]https://www.sporttechie.com/how-the-adidas-micoach-system-has-helped-germany-in-the-world-cup/.

The use of this technology was extended by the International Football Association Board's (IFAB) March 2015 ruling that wearable technology can be worn in regular competitive soccer games,[3] thereby permitting observation of player performances in real and high-stakes decisions rather than only in training environments. Such newly generated information can feed into how tactics are chosen or how players can be trained to be more competitive and stress resistant when it counts. Instant feedback through the use of these wearable technologies could therefore transform how matches are organized in elite sports contexts (Memmert and Rein 2018). Sensoring systems also offer new ways of quantifying performance; for example, a better estimation of speed, acceleration, and force in wheelchair sports to improve mobility performance proxies (van der Slikke et al. 2018).

3 AI Techniques and Quantum Computing

3.1 AI Techniques

Artificial intelligence has come a long way since the 1840s, when Lady Ada Lovelace's prescient ideas for the analytical engine augured the future of AI (Boden 2016). AI and quantum computing provide new ways of more efficiently using computers, applying concepts and models to better understand athletes and their competitors. The application of AI-based methodologies in sports has been discussed in fields as diverse as biomechanics, kinesiology, and the physiology subfield of adaption processes (Lapham and Bartlett 1995; Bartlett 2006; Novatchkov and Baca 2013a, b; Perl 2001; Mężyk and Unold 2011), with the first computerized analysis commercially available as early as 1971 (Lapham and Bartlett 1995).

The artificial neural networks (ANNs) at the core of AI applications, having received substantial hype because of the success of deep learning (Boden 2016), are attractive to the sports environment as a way to model learning (Perl 2001). For example, parallel distributed processing (PDP) has the ability to learn patterns and associations, while not only recognizing incomplete patterns but also tolerating messy evidence via constrained satisfaction (Boden 2016). ANNs are thus relatively well suited to sports applications given this areas' continual battle with large amounts of data, dynamics, and complex input–output relations (McCullagh and Whitfort 2013; Perl and Weber 2004). The applications of ANN are quite broad, ranging from identifying talents and evaluating game strategies to predicting injuries and training loads, or performance in general (Rygula 2003; McCullagh and Whitfort 2013). Experiments by McCullagh and Whitfort (2013), for example, indicate that because ANNs correctly predict injuries to a meaningful level (97.3% for contact and 92.2% for noncontact injuries), they could be used as an additional tool to assess injury potential. While combining such modeling with continuous

[3]https://football-technology.fifa.com/en/media-tiles/epts-1/.

monitoring of longitudinal changes can increase understanding of the multiple injury factors and dynamic nature of injury risks (Verhagen et al. 2014), employing new technologies can establish better treatment and preventive protocols, avoid overuse injuries, and better monitor injury risk factors and symptoms (Verhagen et al. 2014). The specialization of sports biostatistician is thus becoming increasingly relevant in professional sports for both the abilities outlined above and the expertise to design and improve injury surveillance systems, which has prompted some scholars to declare a desperate need to train researchers and practitioners in this field (see, e.g., Casals and Finch 2017).

According to Kahn (2003), ANNs can also be used to predict the outcomes of NFL football games, although the timing of his study toward the end of a season raises questions of efficacy in predicting earlier games. Nevertheless, because the ways in which teams win games are not likely to change over time, the author deemed it rational to assume that statistics from past seasons can be used to train the network. In fact, team sports offer a wide variety of scenarios for network exploration such as the football passes used in Peña and Tuchette's (2012) network theory-based test of the Google algorithm based on knockout stage data from the 2010 FIFA World Cup. These authors defined a team's passing network as one in which team players were the nodes with "connecting arrows between two players weighted by the successful number of passes completed between them" (p. 1). These passes were like links from one website to another and represented the trust put in that player (du Sautoy 2019). Spain not only won the World Cup but reported the highest number of passes, clustering, and clique size, as well as high-end edge connectivity and low betweenness score, all of which reflect "total football" or a *tiki-taka* playing style with no hub (Peña and Tuchette 2012, p. 4).

Expert systems that integrate fuzzy logic processes have also been used to identify sports talent based on knowledge of sport experts, motor skills tests, morphologic characteristic measurements, and/or functional tests (Papić et al. 2009). For example, the implementation of neural network technology to identify explanatory factors in swimming performance (Silva et al. 2007) enabled the development of highly realistic models of predicted performance with elevated prognosis precision (i.e., an error lower than 0.8% between true and estimated performance). This finding implies that neural networks are an effective avenue for dealing with such complex sports problems as performance or talent identification.

3.2 Quantum Computing

The great Richard Feynman (1982) questioned what type of computers would be capable of simulating physics, especially given that although the physical world is quantum mechanical, certain quantum mechanical effects cannot be simulated efficiently on a classical computer (Rieffel and Polak 2000). Nonetheless, quantum computing is a newly emerging field with the potential to dramatically change the way scholars think about complexity (Rieffel and Polak 2000). Major players such as IBM or Google are thus betting heavily on quantum computing, with the former making significant investments in large-scale adoption of quantum computing within their Q Network, a community of Fortune 500 companies, startups, academic institutions, and research labs working to advance quantum computing and explore its practical applications. More recently, IBM opened its quantum computing center, which not only expands the world's largest fleet of quantum computing systems but makes 20-qubit systems for commercial and research activity available beyond the experimental laboratory environment.[4] In a recent *Nature* article, Google scientists announced their achievement of "quantum supremacy" (Arute et al. 2019) based on their quantum computer's ability to carry out calculations that are not only beyond the capabilities of classical supercomputers but would take classical computers an estimated 10,000 years to complete. IBM scholars countered, however, that even given a worst-case scenario, an ideal simulation of the same task could be performed on a classical system in less than three days.[5]

Government agencies are also active in this space, as demonstrated by the UK government's launching of a national program to promote quantum technologies by creating a quantum community destined to become a global leader in this new market (UK National Quantum Technologies Programme 2015).[6] This program, which has received in the first phase 385 million GBP (Knight and Walmsley 2019)[7] from the government, represents a coordinated effort between various departments and initiatives, including the Department for Business, Innovation, and Skills; the Engineering and Physical Science Research Council; Innovate UK; the National Physical Laboratory; the Defence Science and Technology Laboratory; and the Government Communications Headquarters. According to the government, a national network of quantum technology hubs can educate a future workforce and identify the commercial opportunities that quantum technologies can bring to the UK. Popkin (2016), in an article for *Science*, explained why quantum computing can be so powerful[8]:

> Qubits outmuscle classical computer bits thanks to two uniquely quantum effects: superposition and entanglement. Superposition allows a qubit to have a value of not just 0 or 1, but both states at the same time, enabling simultaneous computation. Entanglement enables one qubit to share its state with others separated in space, creating a sort of super-superposition, whereby processing capability doubles with every qubit. An algorithm using, say, five entangled qubits can effectively do 25, or 32, computations at once, whereas a classical computer would have to do those 32 computations in succession. As few as 300 fully entangled qubits could, theoretically, sustain more parallel computations than there are atoms in the universe.

[4]https://newsroom.ibm.com/2019-09-18-IBM-Opens-Quantum-Computation-Center-in-New-York-Brings-Worlds-Largest-Fleet-of-Quantum-Computing-Systems-Online-Unveils-New-53-Qubit-Quantum-System-for-Broad-Use.

[5]https://www.ibm.com/blogs/research/2019/10/on-quantum-supremacy/.

[6]https://iopscience.iop.org/article/10.1088/2058-9565/ab4346.

[7]With a commitment of more than £1Bn over the next 10 years.

[8]https://www.sciencemag.org/news/2016/12/scientists-are-close-building-quantum-computer-can-beat-conventional-one.

Quantum computing and its parallel computations thus promise interesting applications for sports because by breaking the limitations of conventional information structures (Muhammad et al. 2014), quantum information systems open up valuable avenues through which to handle the rich data complexity of the sports ecosystem. For example, miniaturization of quantum technologies can promote new ways for portable sensor devices to increase their monitoring abilities, accuracy, and system integration in day-to-day usage. Likewise, by facilitating tasks that are beyond even the latest supercomputers, quantum computing will enable new ways of analyzing sports-related big data. It could thus dramatically speed up algorithms designed to simultaneously explore vast numbers of different paths (Popkin 2016), a remarkable opportunity for tactical analysis and experimentation in team sports.

Beyond even these impressive advances, quantum technology further offers an interesting alternative to physical sports in the form of quantum games, whose most fascinating aspect is their use of a novel type of physical engine. For example, players in a ball game can evaluate not only one response possibility but a sample of plausible ball trajectories in parallel allowing them to implement more interesting play options (Pohl et al. 2012). Athletes could train on such games to learn and identify new playing strategies.

4 Winning and Fighting with the Strength of Numbers

Sports contests share certain characteristics with military engagements in that both seek victory over others and regularly employ such terms as “beat,” “attack,” “offense,” or “strategy” (Weiss 1969). The search for a comparative advantage in this ferocious positional arms race means that secret weapons can be the difference between defeat and victory: when one team wins, some other team must necessarily lose, making sport the classical winner-take-all market. For example, a player who loses the Wimbledon final in a fifth-set 20-min tiebreaker because of a bad luck or a stupid mistake will just have missed out on 1,175,000 GBP in prize money by being the runner up rather than the winner.[9] Similarly, whereas Olympic gold medalists benefit from lucrative endorsement contracts, runners-up are often quickly forgotten, even if the performance gap between best and second-best is almost too small to measure (Frank and Cook 1995). Hence, although many sports fans may remember Carl Lewis’s four gold medals from the 1984 Summer Olympics (100 m, 200 m, long jump, and 4 × 100 m relay), which matched Jesse Owens’ success at the 1936 Berlin Games, who can name the runners-up in those events? Given this strong incentive to gain a comparative advantage, both athletes and teams are increasingly turning for assistance to the additional technologies of big data and AI.

[9] https://www.wimbledon.com/pdf/Championships2019_Prize_money.pdf.

4.1 Sports Analytics

Nonetheless, whereas digital technologies are now increasingly employed in collecting and improving sports analytic procedures, such analytics and reporting are not new (see, e.g., Morgulev et al. 2018). Baseball, the oldest US professional sport, was one of the first to record its results when in 1854, several decades before the 1869 establishment of the first professional franchise, US newspapers began printing box scores to recap the performances and achievements of amateur baseball contests (Grow and Grow 2017). Why baseball? Because the one-on-one match-ups between batter and pitcher are at the core of the game's action and easier to measure than interactions in other team sports like basketball and ice hockey: "If the batter successfully hits the ball and gets on base, he has 'won' the matchup; conversely, if the pitcher successfully gets the batter out, he is the victor" (Grow and Grow 2017, p. 1572). As early as May 1910, Fullerton's article "The Inside Game," published in *American Magazine*, discussed the science and mathematics (or geometry) of baseball. Then, in 1947, the Brooklyn Dodgers were the first to hire Alan Roth, a full-times statistician previously employed by the National Hockey League, whose statistical insights helped transform the way the game was played[10]:

> "Wouldn't it help a manager," Mr. Roth asked, "if he knew, for example, that a certain batter hit .220 against right-handed pitchers and .300 against left-handers?" Mr. Rickey was intrigued, and Mr. Roth became the first full-time statistician hired by a major league, touching off a trend that has made the personal computer an essential element of clubhouse paraphernalia.

Since the 1960s inception of detailed data recording for both American football and basketball and the 1971 founding of the Society for American Baseball Research, many professional sporting teams have begun investing heavily in analytics departments (Casals and Finch 2017). In England, such record-keeping began when Thorold Charles Reep, frustrated by the slow play and marginalized wingers in soccer, started recording notes that led to his part-time employment as an advisor to Brentford (for an analysis, see Reep and Benjamin 1968). All such sports analytics have generally been interested in new ways of identifying skill, efficiency, and effectiveness measures as a means to deal with the complexity of the sports environment.

In recent years, sports analytics have benefited from better data streaming performance. For example, the real-time systems designed by the IBM CAS-EI analytic team help sports event organizers use big data to provide fans with a more enjoyable data-driven sporting experience via streaming of tweets, scores, schedules, player information, or continual semantic website content update (Baughman et al. 2016). Likewise, the 2016 Australian Open used IBM's Continuous Availability Services to stream social sentiment composed of hybrid clouds,[11] with ongoing fan base reactions and sentiment determined by real-time analysis of tweet

[10] https://www.nytimes.com/1992/03/05/sports/alan-roth-74-dies-baseball-statistician.html.
[11] https://www.ibm.com/blogs/cloud-archive/2016/01/australian-open-2016-streaming-social-sentiment-with-bluemix-hybrid-cloud/.

streams by natural language applications. These applications are but two examples of how the increasing capacities of digital technology to collect, manage, and organize video images can be used to improve sports analytics (Barris and Button 2008).

In fact, sports broadcasting in general has benefited substantially from innovations in computer vision, with some of its best-known current applications allowing TV presenters to explore locations or trajectories in detail (Thomas et al. 2017). Not only can AI systems assist sportswriters in their narrative interpretation of events (Allen et al. 2010), but the new technologies can even overcome the inadequate video and computational facilities in sports stadiums that have caused the long-time failure of automated tracking technology in team sports with rapid interaction (Barris and Button 2008). The use of algorithms via modern big data methods and the increased data availability has allowed the development of new performance factors, such as space control, outplayed opponents, a pressing index based on positional data tracking (Memmert and Rein 2018), and even a potential to quantify "dangerosity" (Link 2018).

4.2 Strategic Elite Athlete Development

Big data and AI can also facilitate the informed development of junior talent, young individuals who may neglect "their studies, skip their violin lessons, pass up opportunities to eat well, and the like, because they desire to be successful or conspicuous in a contest or game" (Weiss 1969, p. 61). Despite such drive, the transition from junior to senior is very challenging, with very few athletes making it to the professional leagues even if trained in an elite sports academy (Schmidt et al. 2017). Yet our understanding of the way in which a successful career develops is limited, as is our knowledge of whether such careers are linked to good performance in junior competition (Passfield and Hopker 2017). New technologies, however, are challenging traditional ways of identifying talent by going beyond the blatantly problematic result-based talent identification (Brouwers et al. 2012). Such technologies can, for example, eliminate potential human perceptual and memory errors like recency and primacy (Eagle and Pentland 2006; Pentland et al. 2009) from the decision process.

In addition, given the greater emphasis in recent decades on adopting a strategic approach to elite athlete development (Brouwers et al. 2012), big data and AI promise new ways of developing appropriate training methods and techniques that take into account the athlete's developmental stage (Kovalchik and Reid 2017). One interesting challenge, for example, is the scaling of sports strategies for children (Buszard et al. 2016), an underdeveloped topic despite an entire book on scaling by Geoffrey West, former President of the Santa Fe Institute (West 2017). According to West, a major challenge for the medical and health industry is to ascertain the quantifiable baseline scale of life; for example, how to scale up new drugs to prescribe a safe and effective human dosage despite the typical experimental cohort being mice. As yet, no comprehensive theory exists of exactly how to accomplish such scaling even though "the pharmaceutical industry devotes enormous resources to addressing it when developing new drugs" (West 2017, p. 52). In sports, scaling of the physical environment through equipment and play area modification (e.g., court size, basket height, or ball size; Buszard et al. 2016) is relatively easy to implement. Yet scaling can also have substantial psychological and emotional influences, especially in the way the environment or training is structured, such as the encouragement of play, feedback, and play intensity through smaller tennis courts with lower nets or the facilitation of skill performance (e.g., stroke-making ability) by lighter racquets (Buszard et al. 2016).

In general, rather than requiring the abandonment or rethinking of earlier decision-making methods, technological developments simply enhance them, as when powerful computerized assessments of players' professional prospects complement the insights of traditional scouts. These technologies can even identify undervalued skills via new performance indicators, such as in the Boston Celtics' use of guard rebounding to identify and pick Rajon Rondo in the 2006 NBA draft from the Phoenix Suns, who only drafted him 21st overall (Morgulev et al. 2018). Rondo has since become a four-time NBA All-Star and has three times led the league in assists per game, earning four NBA All-Defensive Team honors.

4.3 Training and Tactical Analysis

Tactical empirical evaluations emerged as early as the mid-1980s with the adoption of the personal computer (Nevill et al. 2008). Today, the application of big data in professional sports can significantly affect trainers' decisions, to the point that the Washington Nationals replaced a highly experienced and successful but big data-averse manager with a younger colleague who embraced it (Caravelli and Jones 2019). For example, new information gathering processes can offer additional insights into responses to and the effects of exercises, thereby allowing trainers to fine-tune exercise regimes while also taking into account individual characteristics. Likewise, automated player tracking systems can benefit both coaches and athletes in team sports by permitting all stakeholders to examine team interactions and group dynamics in more detail. New technologies can also generate simulations that forecast the implications of team behaviors and biomechanistic or motor control aspects based on intrapersonal coordination and game decision-making (Barris and Button 2008). Yet despite this potential, many sports organizations still prescribe training processes based on experience and intuition (Passfield and Hopker 2017), with core components in existing models of training quantification and its relation to performance based primarily on cardiovascular fitness, strength, skill, and psychology (Taha and Thomas 2003).

Admittedly, however, sophisticated tactical analysis in sports is challenging; especially in team sports, which require not only data accessibility and reliability but also the ability to explore the dynamics of these data and measure them in constantly changing conditions. Yet given the limitations of human computational capacity (Simon 1956), coaches' personal experiences may not be sufficient to develop proper team tactics on a constant basis (e.g., personalized game by game adjustments). Observation-based game analysis is also highly time-consuming (see Rein and Memmert 2016), increasing the primacy of more quantitatively oriented approaches in elite sports like soccer (Carling et al. 2014). As quantum computing and quantum information science break the limitations of conventional information provision (Muhammad et al. 2014), they enable more efficient exploration of the complexity in various settings, testing and simulating various alternatives almost like a "knowledge accelerator." Sophisticated player tracking technologies, in particular, are highly beneficial for fast-paced team sports such as football, basketball, or ice hockey, which can use them to improve training, identify talent, and scout for future players (Thomas et al. 2017).

Another reason for the increasing use of insights from AI or big data to drive in-game strategic decisions (Caravelli and Jones 2019) is the constant public scrutiny of coaches, whose decisions on player insertions, removals, and likelihood to tire, for example, can be greatly assisted by early *warning* diagnostics (Caravelli and Jones 2019): "Today, when one player is substituted for another, he is assessed by how much he does or does not contribute to WAR (wins above replacement)" (p. 111). In the same way, physiological sensoring systems can indicate the effect of an individual's activities even before that individual is consciously aware of what is happening. For example, in a fascinating experiment by Bechara et al. (1997), individuals were faced with four decks of cards, two with small payoffs or losses but a guaranteed profit over time and two with higher payoffs or losses but a guaranteed loss over time. Obviously, when the players began the experiment, they did not know the properties of each deck. The intriguing result was that the players began choosing from the money-making decks before they actually knew why. By monitoring the electrical conductivity of the participants' skin, the researchers determined that skin conductance began to spike when subjects were contemplating playing from the money-losing decks. This unconscious physiological reaction steered their choices away from the losing decks before their conscious rationality was able to figure out why they should behave that way.

5 Prometheus Bound: The Limits of Technology

5.1 What Is Natural?

Because human interaction with technological innovation tends to be challenging, technological advances are always subject to resistance: as Juma (2016) put it, "[t]he quickest way to find out who your enemies are is to try doing something new" (p. 1). In the eighteenth century, for example, longbows were viewed as superior to the early flintlock muskets because arrows were discharged more rapidly than bullets and cost less. In fact, muskets were so inaccurate that soldiers were advised not to shoot until they saw the sclera of the eyes; yet archery required more extensive training than firearms (Juma 2016, p. 15). Similarly, the mechanization of

US agriculture led to conflicts and arguments against the new technology: "There were genuine concerns that the adoption of the tractor would render farmers dependent on urban supplies of expertise, spare parts, fuel, and other inputs that were previously available on the farm. Horses could reproduce themselves, whereas tractors depreciated" (p. 129).

Big data and AI technologies thus reflect an old but nontrivial discussion between the "natural" and the "unnatural" in sports, a pervasive weltanschauung perhaps "best articulated" by Joe Jacobs when "his boxer, Max Schemrling, lost to Jack Sharkey in a highly contested fight: 'We wuz robbed!'" (Greenbaum 2018, p. 32). Yet identifying what is natural or not in the sports environment is extremely challenging given that the technologies discussed here are part of a long tradition of elite athletes using scientific and technological enhancement techniques in a highly complex interplay between genetic predisposition and environmental impact (Loland 2018). Within this tradition, physical training tools are generally acceptable because they maintain "physiological authenticity" (Loland 2018; Greenbaum 2018), but expensive proprietary technology—for example, Fastskin swimsuits—can negatively impact perceived fairness (Greenbaum 2018) and spark fierce debate. In this latter case, within two months of their February 2008 introduction, swimmers wearing Fastskins broke 35 world records. Yet some athletes were blocked from access by price, locked-in sponsorship agreements, or scarcity from overdemand (Zettler 2009). Because data analytics is potentially another technological tool for achieving competitive advantage beyond the natural (Greenbaum 2018), the related proprietary information is highly valued, as reflected by a 2015 FBI (Federal Bureau of Investigation) investigation into whether MLB team St. Louis Cardinals had illegally accessed the rival Houston Astros' computer network.

The constant arguments for a natural approach in the sports environment are particularly understandable in the light of public fascination with how athletes operate at the limits of their bodily capacity in such grueling challenges as the Tour de France mountain stages. Likewise, spectators watch with excitement the human drama of courage, strategy, failed nerves, and/or self-discipline playing out in penalty shoot-outs (Savage and Torgler 2012) or are captivated by the breaking of Olympic records, with achievements compared in different places and at different times (Weiss 1969). It was exciting, for example, to wonder year after year whether and who would beat the monumental 8.90 m long jump (at the 1968 Olympic Games in Mexico City) by Bob Beamon, who actually mis jumped two of his qualifying attempts. The record in fact remained unbroken until Mike Power's 8.95 m jump at the 1991 World Track and Field Championships in Tokyo. Similar excitement followed the feats of Sergey Bubka, a master at record-breaking performances in pole vault, who between 1984 and 1994 slowly increased the world record 17 times outdoors (from 5.85 in May 1984 to 6.14 in July 1994) and 18 times indoors (from 5.81 in January 1984 to 6.15 in February 1993). This incremental progression even prompted one sports commentator (overheard by author) to suggest Bubka's intentional underperformance in regular competition—jumping below the maximum height achieved in training sessions—to build and maintain the suspense for potential world records at major meets.

5.2 Timeless Elements of Sports

To understand the implication of new technologies it might be worth further considering some core elements of sports. For example, why are we willing to repeatedly enjoy a Shakespeare play such as Hamlet, Macbeth, or Romeo and Juliet? Why do we return to classical music concerts listening to Beethoven, Mozart, Bach, Vivaldi, Haydn, or Chopin, but we are not inclined to watch sports games once we know who won? Even hiring superstar actors like Brad Pitt, Tom Cruise, Will Smith, Keanu Reeves, and Leonardo DiCaprio to recreate epic games such as the 1966 World Cup final between England and Germany could not fill a stadium or achieve emotions similar to the actual game. One critical aspect of sporting events is the outcome uncertainty (Rottenberg 1956; Downward and Dawson 2000; Pawlowski 2013; Schreyer et al. 2016, 2017, 2018a, b; Schreyer and Torgler 2018), which prompts organizations in every sport to try and eliminate inequalities where possible and compensate for them where not. Thus in ball games, teams change sides during a game; in alpine skiing, course conditions are adjusted throughout the race, and in technologically driven sports disciplines like motorsports or sailing, equipment technologies are standardized (Loland 2018). For the same reason, many sports leagues, particularly in the US, impose roster limits, pay caps, drug bans, or revenue-sharing arrangements. No matter the precautions, however, the glory days of even the most well-trained athletes are often short-lived, a problem that new technologies might mitigate by enabling athletes to prolong their careers through high fitness maintenance and injury reduction. Nonetheless, even though superstars like soccer players Ronaldo and Messi or tennis players Roger Federer, Rafael Nadal, and Novak Djokovic still dominate their fields in their 30s, it is unclear whether new technologies will allow these superstars to triumph even longer or enable younger athletes to outperform them.

5.3 Too Intrusive?

All the innovations discussed above, but particularly the sensoring instruments, expose athletes' hidden behavioral patterns and intentions, bridging the gap between what they want and what they actually do, and how they interact with others in their environment (Michael and Miller 2013). Not only may such close monitoring be considered highly intrusive, but if not carefully guarded, this massive amount of individual data raises two major risk concerns: hijacking for unscrupulous use in gambling (Greenbaum 2018, p. 33) and negative externalities derived through inexpert data application, which could prematurely end young athletes' careers (see also Greenbaum 2014). Moreover, even beyond the potential biases inherent in coach evaluations and decisions about young athletes' futures (Merkel et al. 2019), overly carefully monitoring could result in meticulous algorithmic manipulation of players like chess pieces across a board. Given that training regimes, particularly under "militaristic" coaches, are already subject to substantial repetitions which provide little room for the inventiveness, daring, surprise, and creativity that delight spectators, these latter have yet to be successfully modeled in the complex interactions of a sports environment.

Nor does technology matter only on the pitch—it also affects stadiums, whose ambience is dependent on spectator attention and behavior. Hence, Mark Cuban, owner of the Dallas Mavericks (NBA), strongly objects to spectator use of smartphone, believing it distracts from the on-court action (Hutchins 2016). For the same reason, a 2014 decision by PSV Eindhoven's club leadership to introduce free Wi-Fi its stadium elicited mixed reactions from fans, with one group so strongly opposed that it unfolded a banner reading "Fuck Wi-Fi, support the team" (Hutchins 2016). This aversion to modern app technology may relate to its influence over how humans act and cope with opportunities and challenges, including fears of losing control over events or being faced with unanticipated outcomes (see, e.g., Gardner and Davis 2013 for youth). Thus, the responses of sports athletes to unexpected events in their more precisely orchestrated strategic environment is an important question that may need investigation in the future.

6 Conclusions

Because of their ability to capture spectators on a visceral level, sports attract huge amounts of financial investment, meaning that the stakes in any improvements are high. It is thus the exciting potential of new technologies like big data, AI, and quantum computing to do things "bigger, better, faster" that has driven their use so far. Even given such "exponential potential," however, grave concerns remain about privacy, inefficiency of effort/time, and hacking. Frank and Cook (1995) even argued that extreme training measures and applications are wasteful from a collective or societal perspective. Why? Because someone will win anyway, whether that person or team trains an hour or four hours per day. Yet new technologies for use in the sports environment are developed specifically for the purpose of winning the positional arms race on the battlefield of the sports arena, meaning that improved performance on both sides of the pitch will eventually be matched and evened out. In any case, humans are better at spotting relative differences than absolute difference. Hence, in two 100 m races with only one runner each, spectators are unlikely to identify a substantial difference between the first race sprinter finishing with the current world record of 9.58 s and the second race runner overshooting the ten-second barrier by a few milliseconds. Nor are they likely to analyze away the very thing that captures them about sports—the surprise, inventiveness, and skill of human effort.

Whether or not sports adopt more technology, attraction to competition as in-group favoritism versus outgroup discrimination is deeply rooted in human nature (Jordan et al. 2014). This human need to be "groupish"—which evolutionarily was conducive to survival and better defense against outgroups—even manifests in infants, who seem to distrust potential playmates with unfamiliar accents (Boyer 2018). Likewise, in the laboratory, if individuals are allocated to meaningless groups (e.g., A vs. B) and then placed in situations of social interactions, they will reciprocate more often with their own in-group (Tajfel 1970).

In addition, as Gigerenzer (2007) demonstrated, intuition or gut feelings are not always a bad thing: fast and frugal heuristics enable adaptive choices in real-world environments with a minimum of time, knowledge, and computation. Human minds have evolved to employ a couple of tricks that are “reasonable enough” Gigerenzer (2007), enabling the catching of a flying baseball or cricket ball in ways that even professionals do not understand. Gigerenzer (2007), for example, recounted the anecdote of a coach who suggested that his players should run as fast as they could to make last-minute corrections but found the strategy unsuccessful. The players also performed poorly when estimating where the ball would strike the ground, a failing for which Gigerenzer proposed a simple rule of thumb: “Fix your gaze on the ball, start running, and adjust your running speed so that the angle of gaze remains constant” (p. 10). This powerful gaze heuristic does not need to take into account all the different and complex parameters such as wind, air resistance, or spin.

Yet even if analytics prove able to tame the element of luck, luck will still remain important in sports as in everyday life, despite some discomfort that it alone might drive success rather than talent and effort (Frank 2016). In fact, the role of luck is amply illustrated by the many highly talented and hardworking athletes who have failed to go professional or launch successful sports careers. One probable contributing factor is tiny initial positive or negative variations that induce positive and negative feedback loops which amplify over time (Frank 2016; De Vany 2004). For instance, would Al Pacino’s career have evolved with another Golden Globe nomination this year at age 79 for his portrayal of Jimmy Hoffa in *The Irishman* if he had not starred in *The Godfather*? Although the answer is only speculative, not only has Pacino clearly benefited from Coppola’s wish to have an unknown actor on board who looked Sicilian (Frank 2016), but 12 other directors were offered the job of directing *The Godfather* before Coppola agreed to take it on.

In general, understanding the limits of technology requires simultaneous consideration of what sports means: why are so many individuals deeply involved in sports and why are they so caught up emotionally in sports events and athletes’ lives. Answering these questions in full would require a philosophical discussion on sports (Weiss 1969), yet philosophers—somewhat like pure mathematicians reluctant to embrace applied mathematics—have mostly failed to explore this topic in detail possibly due to disinterest. Perhaps most agree with Whitehead that the European philosophical tradition is just a series of footnotes to Plato (Weiss 1969), meaning that as the Greeks failed to study sports, it should not be surprising that the philosophy of sports is confined to a few exceptions, such as the work of Weiss (1969). Yet philosophy is not simply concerned with the number of towering geniuses or an obsession with epistemological puzzles like Zeno’s Paradox. Such a focus hinders the ability to see the discipline’s great intellectual potential for explaining the important daily facets of human nature. Yes, Achilles’ race against a lowly tortoise granted a head start is a fascinating problem. Yes, when Achilles covered the initial gap between himself and the tortoise, the tortoise created a new gap. However, failing to handle such problems fully is simply a reflection of human limitations in intuitively applying the tools of thought and exploration (here an understanding of space, time, and motion) in a proper manner. In addition to which the modern thinker is gifted with a wealth of empirical evidence that sports heroes can easily outrun any tortoise.

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The Data Revolution: Cloud Computing, Artificial Intelligence, and Machine Learning in the Future of Sports

Christina Chase

Abstract

Chase argues that data is the currency by which competitive advantage is won and lost. Those who find creative ways to unlock and harness it—largely through employment of Artificial Intelligence, Machine Learning, and Cloud Computing, which she discusses in turn—will be the champions of tomorrow. Use of these technologies will enable a waterfall of new abilities: Teams will better identify talent and optimize training protocols. Game strategy, team lineups, and player archetypes will be created and simulated in virtual "what if" environments. Fans' experiences will be increasingly immersive. If these advanced insights could be properly unlocked, understanding that Artificial Intelligence and Machine Learning are tools with defined limits and biases, data will transform sport and push the limits of human performance.

1 Introduction

As society becomes more reliant on *machine learning* (ML), *artificial intelligence* (AI), and *cloud computing*, so too will sports. As data increasingly becomes the new currency by which competitive advantages are won or lost, those who find creative ways to unlock and harness it will be the champions of tomorrow. Think of the information from an Apple Watch, amplified and with countless professional repercussions.

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Today's teams and athletes have more data being collected on them than ever before. Camera-based player tracking systems such as Second Spectrum, which captures every player's position for every NBA game at 25 frames a second, and sensor-based systems, such as Catapult or Kinexon, which provide 3D-position data in game and in training, have led to an explosion of information. Sports organizations are only now beginning to grapple with these changes. For decades, game and athlete statistics have been collected in sports, but the introduction of these new technologies has led to much larger datasets that offer better situational context to what's taking place on the pitch or the court, unlike ever before.

The rise in these new AI and ML models is fueled by data. The increasing ability to track every second of every play for every athlete in game coupled with the influx of off-field data is driving a virtuous cycle. Indeed, it has become increasingly possible to track every element of an athlete's life, from the stress of training load to in-game load, as well as nutrition and sleep, in the hopes of fine-tuning that competitive edge. Sports are at the forefront as technology is deployed in groundbreaking new ways to recruit players, strategize games, and modernize the fan experience.

I have a front-row seat to this evolution at the MIT Sports Lab. The Sports Lab works with global brands, professional teams, and elite sports organizations in *artificial intelligence* (AI), computer vision, data science, human and institutional behavior, information theory, ML, and statistics, as applied to sports technology and analytics. These brands and professional sports teams enlist us to help them understand and leverage this new onslaught of data.

When we launched in 2015, analytics and player tracking data was in its infancy for many sports. For instance, it wasn't until the 2013–14 season when every NBA basketball arena was outfitted with the STAT SportVU camera systems for player tracking (https://www.ibmbigdatahub.com/blog/taking-data-analytics-hoop). It offered teams the ability to better track and understand the impact and stress on an athlete's body during games and allowed for coaches to conduct strategic and tactical evaluation both of their teams and opponents. Thanks to this technology, they have access to every player's position and play on the court.

In the NFL, RFID chips in athletes' shoulder pads and in the ball (https://www.nytimes.com/2017/09/07/sports/nfl-expands-use-of-chips-in-footballs-promising-data-trove.html) make 10 observations per second, capturing data such as velocity, acceleration, speed, distance, ball flight, and the relative velocity of every player, resulting in about 600,000 rows of data per game. Thanks to this, teams can analyze successes and flaws and predict the outcome of certain plays. Use of this information is in its infancy; many teams simply don't have the bandwidth or knowledge to mine the data to its ultimate advantage.

This growing trove of data, combined with rapidly advancing AI technologies, will be applied in revolutionary ways. AI and ML will bring transformational leaps forward with new insights and predictive power in talent identification. Sports will have access to optimization and design of player training protocols and health and wellness regimes. Game strategy, team lineups, and new player archetypes will be created and simulated in virtual "what if" environments. The power of cloud computing will enable new and exciting immersive fan experiences.

Indeed, if these advanced insights could be properly unlocked, data can push the limits of human performance, helping athletes and teams do remarkable things. These new datasets are already being used to forecast injury in soccer with GPS training data (Rossi et al. 2018), analyzing team passing strategies (Gyarmati and Anguera 2015), and analyzing NBA player shooting styles using body pose (Felsen and Lucey 2017).

2 Opportunities in Sports and Definitions: Cloud Computing, Artificial Intelligence, and Machine Learning

2.1 Cloud Computing

Cloud computing, which is computing infrastructure, allows for large amounts of information to be easily stored and accessed from anywhere in the world. Think of it like the electrical grid that powers the electricity in a house. Once upon a time, if you wanted electric lighting or electric motors in your factory, you had to install a generator. Now someone builds a power plant, which connects it to the electrical grid, and an organization or individual is able to receive electricity on demand. Cloud computing is similar. It's a utility and a centralized, cost-effective resource that's scalable.

Thanks to cloud computing, an organization can collect and store large amounts of data from numerous sources and provide their team with universal access, such as those provided by Amazon AWS, Google Cloud, or Microsoft Azure. Take, for example, a professional sports team in which regional and international scouts are evaluating talent and games around the world. The cloud allows them to quickly upload their latest scouting reports and video from wherever they are into a centralized location; people at HQ access it near real time. This allows for analytics teams to quickly incorporate new information into draft or free agency models and for coaches to analyze games, practices, and players' performance under pressure (https://www.geekwire.com/2019/seattle-seahawks-turn-amazon-web-services-new-cloud-deal-fuel-future-championships/). Teams are using these as the backbone of their analytics capabilities.

2.2 Artificial Intelligence

AI can be broadly defined as machines such as computers perceiving their environment and taking actions to achieve a desired goal. Consider medical software that can read patient X-rays and identify high-priority cases, such as lung nodules, and automatically route results to a pulmonary radiologist, both speeding up the task and helping to reduce errors (https://www.wired.com/2015/10/robot-radiologists-are-going-to-start-analyzing-x-rays/).

There are many forms of AI. Some use statistical techniques to spot patterns and relationships in large pools of data, connecting certain inputs with specific outcomes—for instance, finding connections between genetic mutations and a tendency to be at risk for certain diseases. AI boils down to pattern recognition. Take baseball as an example: After training, computers can be fed video clips without balls or strikes labeled, and a system can classify them into an output answer, ball, or strike. Major League Baseball is now evaluating the TrackMan system to automate umpire assistants with this call (https://www.si.com/mlb/2019/11/19/robot-umpires-automated-strike-zone).

2.3 Machine Learning

One form of AI is machine learning, referring to the process by which a computer system uses millions of data points to learn and improve without human programming. In supervised ML, it's a technique to teach an algorithm to recognize certain patterns. It often uses training data collected from the real world that has been manually labeled by a human, such as identifying pick-and-rolls in basketball.

Rajiv Maheswaran described it best in his TED Talk (https://www.ted.com/talks/rajiv_maheswaran_the_math_behind_basketball_s_wildest_moves/transcript) with the example of training the Second Spectrum ML software to detect pick-and-rolls. "'Here are some pick-and-rolls, and here are some things that are not. Please find a way to tell the difference.' And the key to all of this is to find features that enable it to separate. So, if I was going to teach it the difference between an apple and orange, I might say, 'Why don't you use color or shape?' And the problem that we're solving is, what are those things? What are the key features that let a computer navigate the world of moving dots? So figuring out all these relationships with relative and absolute location, distance, timing, velocities—that's really the key." The power of ML is that a software engineer didn't have to write all of the rules to make that classification; the algorithm learned it independently.

As larger datasets become available, there are more opportunities to use unsupervised ML, where millions of data points that haven't been categorized or classified are used and the algorithm uses its own logic to spot similarities, patterns, or differences without prior knowledge of the athletes or teams.

3 Data Revolution in Sports

We are collecting more data than ever before in sports: High-resolution player movement tracking data for game strategy analysis (https://www.espn.com/nfl/story/_/id/24445965/player-tracking-data-next-step-nfl-analytics-524 revolution; https://www.technologyreview.com/s/600957/big-data-analysis-is-changing-the-nature-of-sports-science/). Game play video from dozens of cameras and angles for better broadcasts. Athlete biometric and physiological measurements to optimize training protocols and health. RFID chips embedded in every NFL player's shoulder pads and in the ball, providing data of every player for every play including location on the field, speed, acceleration, ball flight path, et cetera (https://www.forbes.com/sites/kristidosh/2019/08/06/nfl-renews-with-zebra-technologies-for-on-field-player-tracking-for-next-gen-stats/#1c04819c94ca).

The NBA, meanwhile, employs an optical player tracking system, Second Spectrum, used by teams for pregame scouting, postgame analysis, and by broadcasters though Full Court Press. Fans can choose from four different viewing modes: Coach Mode, Player Mode, Mascot Mode, and a different analysis feed option (https://espnpressroom.com/us/press-releases/2019/02/espn-debuts-the-first-national-broadcast-game-using-second-spectrum-technology-with-its-full-court-press-view-during-fridays-bucks-lakers-matchup/).

4 The Game: Player Identification, Evaluation, and Selection

In the future, AI will be able to synthesize scouting reports, advanced game statistics, performance testing, training loads, injury reports, personality profiles, and more to predict how players might develop and whose talents they might mimic by modeling their potential development, answering: "Who might be the next Tom Brady?" Brady, selected in the sixth round of the NFL draft, went under the radar of almost every pro scout. Today he's widely regarded as one of the best quarterbacks to have ever played the game. How could he have been so drastically overlooked? Easy. He didn't fit the profile of what an NFL player should look like. He was small, not seen as nimble or quick on his feet, and was perceived as lacking throwing accuracy (https://theathletic.com/1235430/?source=twittersf). Meanwhile, ML models have been developed to inform player rankings in soccer (Brooks et al. 2016), decide how much NFL players should be paid (https://www.businessinsider.com/nfl-using-ai-player-salaries-pro-football-focus-2019-7), and to scout players at the college and pro level (https://www.nbcnews.com/mach/science/how-ai-helping-sports-teams-scout-star-players-ncna882516).

What does this mean for future scouting? As more historical data is available on successful players, such as scouting reports, physiological and mental test data, and team workouts, it could give teams the training information they need to build new ML models to identify typically unrecognizable potential of young athletes.

The current challenge is that so much data exists. Humans cannot see a signal through the noise. In the future, just as AI can help radiologists detect patterns invisible to the human eye, it will soon be able to detect patterns among athletes: shooting characteristics, coachability, work ethic, and more. Just as Facebook can curate the types of posts viewers see, so too can future sports technologies. This is exciting because, historically, recruiting was deeply dependent on whether a recruiter was at the game and observed an athlete. Now, scouts are able to quickly collect mountains of film, video, et cetera, and quickly upload it so analytics teams can immediately access this new data and inform the draft and free agency models they're working on, often using in-house platforms that will be able to analyze and synthesize data. Many baseball clubs have built this out, with basketball and football to follow. New data could inform future draft models, and those who take advantage of the new data sets and dig out the most pertinent information within them are going to be at the forefront. There are jobs that will come into existence that don't exist today. For instance, NFL teams hired 11 people participating in their 2018 Big Data Bowl for new analytics roles (https://www.zerohedge.com/news/2019-12-25/quants-are-taking-over-nfl).

ML will also play a role in investigating interpersonal dynamics. Teams need to know a player's athletic potential, but they also want to be able to evaluate the personal and mental aspects of a player: How will s/he affect the locker room? How coachable is s/he? How does s/he make decisions under pressure? Teams will be better able to evaluate "culture fit" as GMs decide on critical draft picks or free agency contracts. The ability to quantify the seemingly unquantifiable is on the horizon; in fact, this research is already happening in self-driving cars, in which driving behavior can be classified with respect to how selfish or selfless a particular driver is (https://news.mit.edu/2019/predicting-driving-personalities-1118).

Similarly, the MIT Sports Lab recently examined the five key positions in basketball. The skills needed in these roles have changed as the rules of the game have evolved. Consider Stephen Curry, who in the 2009 NBA draft, was seen as having a frail frame and stuck between a one and two and became one of the best three-point shooters ever. Thus, we used "clustering" to create new archetypes for players. Using Second Spectrum data, we were able to define the new "roles." We then selected the top three teams and bottom three teams to evaluate how their lineups aligned with these new skills. We examined patterns among the top and bottom three, clustering athletes based on skill and categorized them in buckets. Which combination of skills is the most effective in modern basketball? Technology will help coaches group these athletes to predict development potential. This will sharpen draft and free agency models and be used to counter opponent behavior.

5 Optimizing for the Win: Game Strategy

Leveraging new technology, the question becomes: How do I reverse engineer my opponent's playbook and coach proactively? Today, numerous hours are spent watching film of opponents. In the future, a successful team will allow a computer to track an opponent's strategies, quickly create that highlight reel, and then allow a coach to design plays around it. Meanwhile, coaches will also be able to mold a team based on their individual models using virtual, simulated environments, not unlike a video game. A user uploads a virtual team and the characteristics of an opposing team, runs simulations, and examines which strategies work—and then takes it to the field.

Labeling tracking data is now a standard use of AI in the NBA. This has opened a flood of data that can now provide ML models with the information they need to start to recognize patterns of an opponent's play sequences and recommend winning strategies. New models are predicting player trajectories (Felsen et al. 2018) leading to the ability to do real-time interactive play sketching of NBA defenses (Le et al. 2017). This is changing how players are being evaluated, team strategies are being informed, and even how we look at the game.

We're already working on ways to quantify the optimal setup for a goal or the best person to pass to in a certain situation. Soon, we will be able to visualize what sequence of small events led to an optimal shot, identifying opponents' strategic tendencies and ultimately reverse-engineering their playbooks.

In this future virtual simulation model, not only does a coach begin to better understand opponents' tendencies, but he or she can also identify their own team's weaknesses and work accordingly to optimizing trainings. A coach will also be able to create virtual models to try different strategies and tweak accordingly.

Data is the key here, again. The more data gathered on these athletes, the more we can extract structured data on inputs and outputs—pitches, balls, strikes—and the better we can create an accurate virtual simulation (https://news.mit.edu/2019/deeprole-ai-beat-humans-role-games-1120). In the future, AI systems will improve themselves. Already, AI algorithms are being developed to compete. So-called generative adversarial networks (GAN) (arXiv:1406.2661) can be created to play out in-game scenarios. In a GAN, two AI algorithms compete with each other and improve along the way.

While it seems futuristic, an adversarial network has already been used to analyze basketball playing—give it an offensive set play sketch, for example, and it will suggest potential scenarios of play. In the future, we may be able to play out in simulation how a whole lineup will or should react to an opponent's specific lineup (Hsieh et al. 2019).

Self-learning AI models can also discover entirely new game strategies. Alpha Go, the AI algorithm that beat the best human champions at the game of Go, learned to become better by playing millions of games against itself, and along the way discovered previously unknown winning strategies.

In the next ten years, maybe sooner, we'll also see digital twins used to play out "what if" scenarios in virtual environments. A digital twin (https://en.wikipedia.org/wiki/Digital_twin) is a digital representation of a real-world object, a set of data that represents its properties, characteristics, and behavior. Digital twins emerged in the industrial world. For example, a digital twin of a power plant can be used as a virtual proxy to simulate, analyze, and optimize the performance of the real-world power plant. These industrial versions of digital twins create virtual proxies of physical objects, and the concept can also be applied to people.

In sports, this could create questions such as: What if we substituted another player into the lineup? Imagine an accurate digital twin of a team lineup that can play endlessly within a software simulation against a simulation of an opposing team (https://www.techworld.com/tech-innovation/digital-twins-of-athletes-next-frontier-for-sports-3777364/): "Computer, play my team against the Celtics for five seasons." Imagine a coach and staff trying out new variations of game strategy, lineups, and variations of player abilities or even variations on player training, nutrition, and load to examine how those could affect player performance. Or, with GANs, a machine could independently find new winning strategies.

AI could also suggest which small biomechanical changes would have the most significant impact on performance. One early system from MIT can look at a photo of someone swinging a tennis racket and then offer a proposed new pose for that person. This can potentially allow players to see themselves, projected, using the correct form (https://www.csail.mit.edu/news/put-any-person-any-pose).

6 Athlete Health and Performance

Much like a Formula 1 racecar, athletes are singularly driven and rigorously monitored. Every single part and piece on such a car is known, tracked, and measured. The same is becoming true for today's athletes, as we've discussed. For example, envision a basketball team that tracks workouts: An athlete checks in on an iPad and performs the workout tailored to him, which is then captured by the gym machines and fed into a system that marries it with estimates of load from training.

In the future, sports scientists and performance coaches will use digital twins to test these effects in a simulated environment. The NFL has just started this work to better understand player safety and treatment by analyzing game rules, equipment, and rehabilitation strategies in the hopes of better forecasting the risk of injury (https://www.ciodive.com/news/NFL-AWS-AI-ML-safety/568619/). Creating virtual models of their athletes, they could experiment with increasing or decreasing an athlete's practice schedule, weight training, nutrition, medications, sleep, travel, and time zone changes to see how their bodies react. They could quickly test and iterate in a virtual setting to examine the effect of different changes, rather than iterating on the human, resulting in quicker information.

With all of this new data, teams are increasingly considering ways to optimize the performance of their athletes and how best to keep them in peak condition. All of this new data is helping sports scientists quantify the reasoning behind a recommendation for an athlete's load management. By combining in-game player tracking data, such as Second Spectrum, with tracking systems worn in training, such as Catapult or Kinexon, as well as biometric testing and strength and conditioning workouts, high-performance groups will increasingly have more tools to maintain athletes' health. They will know when it's time to recommend rest or replacement of an athlete, even though they may not be officially injured, or when to replace their starting pitchers (https://chbrown.github.io/kdd-2013-usb/kdd/p973.pdf; New data shows baseball managers when to replace the starting pitcher. https://phys.org/news/2014-02-baseball-pitcher.html).

Using pose estimates to detect changes in their athletes' biomechanics imperceptible to the eye could indicate whether someone is over-trained or not fully recovered from injury, leaving room for vulnerability (Bridgeman et al. 2019). With additional data collected from athletes over the years, this could give teams the ability to analyze the development of an athlete over time, to devise an optimal development pathway, and to deduce how training should look during a similar athlete's career.

In the future, we will have a better ability to pinpoint increased risks of potential injury by picking up or recognizing patterns for a particular athlete.

7 Smart Venues and Stadiums

Stadiums are also changing. Yesterday's stadium had multiple gate entrances with a paper ticket. Teams and venue owners had no idea what a fan did while in the stadium, or even who was there. Now, they're moving to digital tickets whereby it's known exactly who's in the stadium, where they're buying food, how often they're looking at the game, and how engaged they are.

Now we're able to track flow and understand how to optimize for particular user groups and personas (https://news.sap.com/2018/10/executive-huddle-sap-helps-49ers-improve-operations-fan-564 experience/).

Stadium and venue owners are looking for new ways to create "an experience within the experience." You see pop-up selfie stands. There's now the ability to control cameras in the rafters to take a picture right at a fan's seat, do a close-up, and then tweet it out instantaneously. The goal is to entice more fans to come to the stadium (https://www.forbes.com/sites/davidramil/2020/01/13/miami-heat-innovation-with-data-leads-to-agreement-with-bucks/#ad5a91e7174a) and to personalize the experience so that they come back again and again (https://www.forbes.com/sites/davidramil/2020/01/13/miami-heat-innovation-with-data-leads-to-agreement-with-bucks/#ad5a91e7174a).

8 Personalized Consumption of Sport

Excitingly, fans also have access to this information now more than ever. Consider again Next Gen Stats in the NFL. Now, a fan can examine all of Patrick Mahomes' passes for the 2018–2019 season to see how many yards were passed and visualize those passes—who he passed to and their routes. Today's fan is able to dive deeply into insights around their favorite teams or favorite players. They can visualize information and also the stats themselves, which were never accessed before (https://www.techrepublic.com/article/how-the-nfl-and-amazon-unleashed-next-gen-stats-to-grok-football-games/).

Or consider Clippers Court Vision (https://www.nba.com/clippers/clippers-introduce-revolutionary-technology-launch-clippers-courtvision-digital-viewing-experience) and ESPN's branded Full Court Press (https://www.forbes.com/sites/simonogus/2019/05/26/augmented-reality-options-by-second-spectrum-added-to-espn-app-for-nba-playoffs/#6a0ecbfa3db4), where a fan can, from three or four modes of viewership for Clippers games, decide: What's the additional overlay of augmented viewing experience that I'd like? Before it was merely the broadcast game, but now a fan can see it from the vantage of whomever has the ball. Already, the NFL's "Be The Player" (https://www.sporttechie.com/intel-to-deploy-new-be-the-player-broadcast-feature-in-super-bowl-li-partners-with-patriots-qb-tom-brady/) uses more than 100 cameras placed around the field connected with five miles of fiber-optic cable to capture and synthesize video to let fans see the action from any player's point of view. Viewers will continue to have new ways to personalize how they consume, watch, and engage with sport.

Customization will be paramount, similar to customized Google alerts or curated Instagram feeds. Innovations from the world of information display will let fans mix and match personalized floating windows of stats, turn on graphic overlays that track plays and automatically highlight players and plays, and build their own viewing experience. Personal choices will be remembered, shared, and used to automatically improve the experience in any setting—whether in broadcasts, in virtual reality, or augmented reality overlaid on live action in smart stadiums, which Microsoft has done with its HoloLens (https://www.wsj.com/articles/the-future-of-sports-is-interactive-immersive-and-intense-11552827600). Moreover, the future of fan engagement will be far more seamless and customizable. For example, AI and ML will be used to possibly create and personalize highlight reels for fantasy football teams.

Ultimately, a fan could watch TV at home and feel as though he's on the 25-yard line with the New England Patriots. Consider this: Today, a fan might attend a football game and use a paperless, digitized ticket on a phone. He'll enter the stadium, buy a hotdog, sit down, cheer, and see some basic stats on a Jumbotron. In the future, likely within a decade, if a team is at an away game, a fan might go to the home stadium and through virtual reality feel as though they have the best seat in the stadium at the away game, in real time. Nobody is actually playing on the field, yet it's fully immersive thanks to a tiny virtual reality headset, right down to the roar of the crowd.

Imagine what Google Glass was trying to achieve, but with personalized augmented overlays that customize viewing experiences in a stadium. Now, let's imagine you're at home, and a group wants to watch the Patriots game, but you're distributed around the world. Soon, you will be able to enter a virtual setting whereby you're sitting in the stadium together watching the game, communicating in real time. As such, there will be new, exclusive experiences, which might cost more. But there will also be new and different ways for fans to engage through virtual worlds and new opportunities for teams to grow fan bases around the world. And as technology scales these heights, sports break down boundaries and unite a community that transcends demographics, economic backgrounds, or religion. It's an interesting and wonderful way of breaking down those barriers and finding community and commonality across all walks of life.

9 Ethical Implications

As we stand at this brink, data is exciting and powerful. But there are also challenges and ethical implications. Scouts and sports scientists can collaborate from anywhere. A team might have hundreds of scouts who are looking at junior high, high school, college, international, and pro athletes around the world and need to create a roster for each. A team has video coming in from scouts, trainers putting in workouts, coaches tracking game stats, batting coaches, hitting coaches, strength and conditioning coaches. Thanks to cloud computing, data is being collected and put into one place and new data or insights are being generated. This is effective and it's dangerous. Any time one has the ability to access data at different levels of privacy, it naturally opens up a chink in the armor by which people might be able to access information they shouldn't—because it's now in a shared system, even if it shouldn't be shared.

In the past, information such as sleep, injury, or how a player might be evaluated internally was private—but now, people could hack into this shared resource. Think of it like the Equifax breach: As connectivity increases, the more opportunities exist for openings along that stream for somebody to access the entire network.

There are also ethical questions around using AI and ML to make bad predictions. Say you're trying to decide whether to renew a contract for a free agent. You're collecting data from sports scientists on workout and the athlete's recovery. But then you also have their electronic medical record, mental health, and sleep data. Perhaps an international scout has access to an athlete's personal medical record due to flimsy security authorization access, and they unearthed that this athlete has a particular biomarker for Parkinson's disease. Is this disclosed?

Meanwhile, AI and ML techniques bring with them an inherent bias. Of course, all data has an inherent bias associated with it (http://gendershades.org/overview.html; https://venturebeat.com/2018/12/21/researchers-expose-biases-in-datasets-used-to-train-ai-models/). If that bias isn't understood, then there's a high risk of a bias being amplified by this type of technique. For example, if an individual applies for a loan, an algorithm decides whether that person is at risk for default. If data shows that Caucasian males are promising candidates for loans and young females (of any race) aren't, it might simply mean that there's no data or not a big enough sample of young females in that data set—not that they're unworthy. Ultimately, it comes down to understanding what data has been collected, having enough data, understanding how it's been taken into the system, maintaining standardization with labeling and analysis, and being mindful of any biases potentially introduced along the way (https://www.csail.mit.edu/news/ai-de-biases-algorithms; https://www.microsoft.com/en-us/research/blog/are-all-samples-created-equal-boosting-generative-models-via-importance-weighting/?OCID=msr_blog_genmodels_neurips_hero; Grover et al. 2019).

AI is a tool, not an answer. A recent MIT CSAIL article stated "…regarding AI as a truly singular technology is a mistake, one that puts us at risk of missing out on its potential while also inviting algorithmic dystopia (https://www.csail.mit.

edu/news/wapo-op-ed-how-regulate-ai-properly)." It's adept at recognizing large patterns. Elite athletes are naturally outliers. Therefore, one could miss some of the best prospects because these techniques are misunderstood. There are also human outliers, and so something may not be picked up or biometric baselines might be very different than those found in an average individual. This, too, could lead to false conclusions with performance, health, and potential. AI is trained to look for patterns, and when patterns don't exist, it's confounded.

Consider Facebook. Initially, users thought that their feed was being lightly curated, simply eliminating some information. Instead, it was amplifying reposts or retweets, et cetera, that it assumed the user wanted. While detection of fake news is being worked on (https://www.csail.mit.edu/news/better-fact-checking-fake-news), better ways to confuse the algorithms continue to be developed.

The proliferation of videos doctored by AI is called "deepfakes," or fake information that is put forth as real. It looks credible and is impossible to distinguish by a computer, which could easily bring down an athlete (https://www.csail.mit.edu/news/new-film-highlights-dangers-deepfakes-shaping-alternative-histories). The key lies in understanding when and how to use these techniques. A computer isn't intelligent; humans are intelligent. They cannot replace a human. Therefore, humans must understand inherent bias.

There are also legal and ethical ramifications (Karkazis and Fishman 2017; https://go.forrester.com/blogs/the-growing-legal-and-regulatory-implications-of-collecting-biometric-data/). Right now, biometric data sits outside of US HIPAA regulations of electronic medical records. Unclear federal and state health privacy laws for biometric data could influence the ability of a player to take any biometric data with them if traded. It's not clear who owns this data and whether a player could take the data with them if traded.

League data-sharing policies, as well as potential conflicts of interest and dual loyalty, could have implications around contract negotiations and privacy. Players might not know what data has been collected about them. We see these conversations starting to take place. For example, the National Basketball Players Association recently negotiated that data collected from wearable devices could not be used for contract negotiations (https://www.mintz.com/insights-center/viewpoints/2186/2017-12-athletes-and-their-biometric-data-who-owns-it-and-how-it).

That's why using AI and ML aren't an answer; they're a tool. Understand that the potential bias and the potential risk of influencing outcomes adversely can be high without understanding a model's weaknesses. Understand that any time information is collected on an individual, increased surveillance is a natural threat to privacy and confidentiality. The risks around security and access are not to be underestimated. A sporting organization needs to care about security as much or more than a bank.

It's now the Wild West, because so much data has never existed before and new sources continue to become available. Indeed, there's an opportunity in being able to get a better holistic view of an athlete to optimize performance. The flip side is suddenly having mental, physical, and psychological data for an individual sitting in one place that isn't secured and uncovered by HIPAA. This could ruin a career. Smart sports organizations will hire analytics teams who know how to wield it appropriately.

This is why it's important for any analytics team to understand the ethical and moral aspects of human analysis. Broader conversations and agreements should define clear protocols around collection, access, privacy, and usage. It will take thoughtful conversations with all stakeholders and should include neutral third-party experts to ensure everyone understands the implications. Since sport is a social microcosm, the outcomes of these discussions will likely inform broader public policy. Don't take this lightly.

At the same time, this data could make sports more exciting and nuanced than ever before—and as goes sports, so goes society. The data you collect on an Apple Watch, for instance, could change the sport you love in countless ways. This information opens up a new world of human understanding, competitiveness, and behavior. It's just the beginning.

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Blockchain: From Fintech to the Future of Sport

Sandy Khaund

Abstract

In this chapter, Khaund gives an explanation of the oft spoken about but little understood blockchain. He walks the reader through likely applications of the blockchain technology on and off the sporting field taking time to outline the revolutionary power of smart contracts for athlete compensation, gambling, and even broadcasting contracts. He argues that anywhere transactions between multiple parties occur or privileged management of data exists, blockchain will become the de facto solution and even lead to new business models. In his view, the short-term benefits will be limited by the willingness of the incumbents to accept drastic change, but the long-term future of sports will be assuredly and profoundly impacted by blockchain.

1 Introduction

With its origin as an inaugural white paper submitted in 2008 by an individual (or perhaps a group of individuals) who went under the pseudonym Satoshi Nakamoto, blockchain has been touted as a disruptor in the financial markets by replacing traditional government-issued currencies with a universal, digital-native format. It is fair to say that any innovation that will reduce the friction of financial transactions, whether through the reduction of intermediaries or the ability to more effectively cross global boundaries, has unlimited potential. However, perhaps the only thing more mystifying than understanding the value of blockchain is understanding the blockchain itself. Through a set of cryptographic algorithms that run against a series

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of networked computers that cooperate to validate transactions, blockchain leverages many technologies that are not traditionally understood by the general public. This lack of understanding of the technology only adds to the skepticism of people who are considering its use. In that sense, blockchain faces a burden of proof that is rarely encountered by other technologies. After all, can anyone truly explain the inner workings of a relational database? Yet we've grown to trust it and assume that it will deliver on its promise as a technology. Not so with blockchain.

With that said, a cursory understanding of the blockchain technology and its different permutations and how they will be applied is an important foundation before we discuss its application to sports.

2 Blockchain Background

Perhaps one of the most important things to understand about blockchain is that there are different permutations with different attributes that greatly affect the intended applications that it will support. The seminal blockchain that started it all is bitcoin. While blockchains have evolved beyond the fundamental capabilities of bitcoin to the use of smart contracts, it is still important to appreciate the core principles of bitcoin.

2.1 Bitcoin and Cryptocurrencies

From the application space, bitcoin's utility is clear: It allows people to exchange currency on a digital platform, like the internet, anonymously and without intermediaries.

So how does bitcoin work?

The most important thing to understand is that the bitcoin manages a series of debits and credits around a finite set of values. In the same way an accounting ledger tracks a bank account's inflows and outflows, bitcoin manages everyone's balance; and value can be transferred from one person to another. So, when Amy wants to give Bob 10 USD, the blockchain confirms that Amy has 10 USD to give; then, in the transaction, 10 USD are debited from Amy's account and credited to Bob's account. Only, instead of dollars, the value exchanged is in a unit called a "bitcoin." Bitcoins are effectively infinitely divisible, and the lowest atomic unit is a "Satoshi." So, given bitcoin has ranged anywhere from 3,000–10,000 USD over the last year, most transactions will be a fraction of a bitcoin; instead of 10 USD, Amy gives Bob.001 bitcoins.

So, you say, "big deal, Amy and Bob can do that using Venmo, right?"

That's true, but for business transactions, Venmo (or Visa, MasterCard, etc.) will take a healthy fee for that transaction. In addition, the privacy of the transaction is compromised and there's no way to perform an anonymous transaction. Bitcoin allows for anonymous transactions where you are only identified by what is called a public key, a string of hexadecimal digits that represents your "address," similar to a username, and a separate, private key, a longer hex string that acts as your password. The combination of public and private keys is unique and completely random, so they have no association with the user. Among other things, this helps establish anonymity.

Only this public–private key pair can authorize a transaction on bitcoin as every public key can only be controlled by one private key. When Amy wishes to send money to Bob, she uses her randomly defined private key to encrypt the transaction, and a network of participating computers assess the validity of the transaction and provide confirmation. Ultimately, to quote the tagline of Sun Microsystems from many years ago, "the network is the computer."

Cryptocurrencies have become the backbone of blockchain applications. Bitcoin continues to be the most popular among them, though there are others like Ripple, Dogecoin, and thousands of others, that focus on trying to create their own currency as a replacement for cash and credit. As a proxy for currency, the overwhelming application of bitcoin seems to be more along the lines of speculation against government-issued ("fiat") currency, similar to gold. However, once volatility begins to subside, there is a case to be made that they will ultimately become transactional like a dollar bill or a euro. Several currencies have attempted to pin valuation to fiat currency. To discuss the evolution of these cryptocurrencies would warrant a separate book and many have been written already. For the purposes of this discussion, the important takeaway is that billions of dollars have been transacted across these blockchain-based currencies and the original premise of Satoshi Nakamoto has stayed true to its promise.

2.2 Smart Contracts

While bitcoin and other currencies have tremendous value in the financial space, there is another benefit to blockchain: *smart contracts*. The easiest way to think about a smart contract versus a bitcoin is to think about a credit card versus cash. Cash is great, it provides an important service, but it is limited in its functionality. A dollar bill is just a dollar. It serves no other purpose. But a credit card has many more variants. It can not only be one dollar, but it can be many dollars depending on your spending limit. In addition, it can be a loyalty program, a form of identification, a deposit for a hotel room, and many other things. The flexibility of a credit card is determined by the issuer in covenant with the cardholder. The credit card has attributes, restrictions, and policies that are specific to the card.

Smart contracts digitally and deterministically define a relationship between multiple parties. As you'll see in the upcoming examples, providing a smart contract with data can trigger actions, reset state, and execute agreements (legal and otherwise). As an evolution of data storage, it becomes an autonomous, asymmetric asset (as opposed to most SQL database that have symmetric data form and rely on external systems to manipulate the data). In technical terms, it acts as a state machine.

As you will see, sport is made up of many agreements, whether it's the athlete and the team for which he or she plays, the spectator and the broadcaster of the event, or even a gambler and the bookkeeper who manages the bets. Blockchain allows the transactions between these parties to be automated, transparent, and frictionless.

To appreciate the value of blockchain in any ecosystem, it's important to understand that its greatest impact will happen in coordination with other technologies. A blockchain is made up of a series of templates of data and triggers that, in the sport sense, could be orchestrated by a host of internet of things devices. In addition, blockchain can be responsible for generating and evaluating sufficient data to allow artificial intelligence systems to make subsequent decisions. Blockchain is excellent for microtransactions and small dealings, but the ability to aggregate transaction data and turn it into actionable consequences is where it can really find its value. In some of the scenarios that we present, you'll see a strong complement between blockchain and other emerging technologies that will change the face of sports.

3 Blockchain in Sports

With a basic understanding of blockchain principles, both as a network of distributed computers that validates transactions and the introduction of smart contracts as a means of digitally enforcing agreements based on changes in data, we will now investigate several potential applications of this growing technology in the world of sports over the next five to ten years.

3.1 On the Field

The first area of blockchain applications that we will focus on will be on the playing field. As athletic competitions increase in their quantification, the ability for that data to be used for assessment and analytics continues to grow. One question that will grow increasingly prevalent is how to verify and validate the recorded data and, subsequently, how to manage access to that data. The cryptographic algorithms of blockchain will play a pivotal role in enabling a trustless system of data capture and dissemination.

3.1.1 Recruiting/Assessment

Take, for example, the very sophisticated domain of college recruiting. Currently, hundreds of college coaches traverse the world, seeking a future set of athletes that will bring them to glory. Attempting to assess a 17-year-old athlete by visiting a school and watching a game has never been a scalable proposition. Just as employers often show a preference for Ivy League schools because it is easier to focus on "safe" sources of talent, many college coaches limit their quest to top schools or recruiting services. However, it's very difficult for an athlete outside of that high stratosphere to establish themselves as a legitimate prospect. Therefore, many great players end up never getting recruited. For every LeBron James, who was anointed from an early age as the next great basketball superstar, there is a Steph Curry, who was virtually unrecruited despite having a professional basketball player as a father. Curry was dismissed easily due to his diminutive stature and the level of competition that he faced in high school. One wonders whether proper data capture, irrespective of traditional measurements like size and competitive opponents, could have predicted that Curry would become arguably the greatest pure shooter in NBA history.

The capture of data via internet of things will create a scalable model for recruiting, but what of the data once it has been collected? And how do you validate that the performance data has not been tampered with? The stakes are high—with shoe deals and broadcast rights turning amateur athletics into a multi-billion-dollar business. Can the data be collected and trusted—tamper-proof from overzealous parents that wish to tweak the data to boost their child's ability to gain a scholarship?

In addition, from the player's perspective, this data should not necessarily be completely public. The player is afforded the right to privacy; so, he should be aware of which coaches seek to access his data. In addition, access should be limited because opposing coaches could use the data for strategic purposes, which would be counterproductive to the data producer. How does one manage access to data without involving a third-party?

The validation and subsequent securitization of data is a hallmark of blockchain. The ability for measurement devices to securely package and confirm the data is important to provide provenance. In addition, a smart contract has the ability to expose data to a subset of individuals and, if necessary, track the monitoring of the data. Particularly in organizations such as the NCAA, this will be a valuable way to monitor the recruiting behavior of institutions.

3.1.2 Player Compensation

Of course, while recruiting will create interesting uses of data and analytics, there is a much more prominent opportunity once the player is secured and part of an organization. The quantification of the data should play a role in compensation. Currently, many sports contracts are tied to incentives. Major-league pitchers are often given bonuses based on the number of innings pitched and the number of appearances in a season. NFL running backs are often paid incentives based on the number of yards gained, regardless of when or how those yards are gained. These coarse metrics often create issues around aligned incentives. For example, in 2017, Minnesota Twins pitcher Phil Hughes was one inning short of an incentive that would have paid him millions of additional dollars. While the Twins would likely insist that they did not intentionally avoid the incentive, it's safe to say that these thresholds can be exploited. So, how will teams make compensation based on performance more granular and automated? The answer is smart contracts.

As we described before, the quantification of performance is rising and can go well beyond the coarse numbers that have typically driven incentives. The ability to capture that data and trigger compensation in exchange for performance becomes an intriguing opportunity. The amazing analytics that are used in sports right now show the probability of a play being performed. Therefore, when Angels center-fielder Mike Trout goes into the gap to make a diving catch, an analytics engine called Statcast tells us that there is a nine percent chance that ball will be caught. Before, the play would simply be marked as a fly out to centerfield and someone keeping score would put a star next to the play. But in the rich annals of baseball history, it would be as impressive as a routine "can of corn" that was hit on the very next play. But what if Mike Trout got a bonus every time he made a sub-10% probability play?

Building a contract that issues payment based on triggers of unique micro-transactions is a very viable use of blockchain. There may be a concern about putting a premium on individual performance over the team's performance, but it is be mitigated by utilizing a perpetual metric in sports defined as winning probability. If each player is measured and winning probability is reassessed after every play, it's conceivable that any time a player achieves a play that moves the win probability significantly in his team's direction, he is rewarded.

It's worth noting that the ability to do these things does not necessarily match the likelihood that they will happen, especially in sports where there is a long legacy of how players are compensated. As we will explore at the end of the chapter, the challenge of adoption may prove more challenging than the technology itself. However, knowing that it *can* happen leaves the possibility that more forward-thinking organizations may be able to experiment with this—especially in places where there are fewer legacy practices, such as esports.

3.2 Off the Field

While the applications of blockchain will be impactful when it comes to on-field performance, the revenue typically comes from the fans in the stands and beyond.

3.2.1 Gambling

Perhaps one of the most controversial sports topics is betting. For years, restrictions on gambling have plagued the industry. While regional support for gambling in areas such as Nevada and Atlantic City have created opportunities for people to partake in sports gambling, limited access to these channels has left a significant amount of opportunity on the table. However, the internet has become a lightning rod for controversy on whether internet players must adhere to the same policies—or any policies at all.

Several years ago, startups Draft Kings and FanDuel both achieved astronomical growth when they created a conduit for sports betting through fantasy sports. The argument was that this was not gambling, but a game with an entry fee and prizes. While that was ultimately something for the courts to decide, the outsized demand for these types of games essentially validated the premise that sports gambling generates transformational revenue for businesses and leagues. Recently, court cases in the Supreme Court have opened the door for legalized internet gambling. Much like the discussion of cryptocurrency as a viable means of performing transactions, the discussion of internet gambling could warrant its own book. For the purposes of this discussion, we will safely assert that the demand is undeniable, and the implementation (particularly online) still needs work.

Blockchain will reduce friction in sports betting and even become the ultimate "bookie." Smart contracts act as a deterministic arbiter of a legal contract. Ultimately, a wager between two people (or a person and his bookkeeper) on the outcome of the game is a social legal contract. A smart contract can be written to hold the funds in escrow and payout once the outcome of a game is completed and certified. Any additional nuance in the bet (whether a party can withdraw before the game starts, whether the terms can change based on a late injury, etc.) can also be encoded in this smart contract. If done publicly, these transactions are transparent. Depending on who you ask, that could be a very good or a very bad thing. For government regulators who want to make sure that gambling winnings are reported, the trail of transactions would all but guarantee reporting. For the gambler who doesn't want anyone to steal his strategy, it may not work as well. Designing a smart contract where only certain parties have access to the information within the bet is another approach to implement online sports betting in a way that satisfies the participants as well as government authorities.

3.3 Off Game Times

While game time is when the action happens, there is an entire set of businesses that rely on everything that happens before and after the game. Not surprisingly, blockchain will play a role in many of these businesses.

3.4 Memorabilia

Sports memorabilia is an enormous business. From autographed pictures and game-used equipment to a famous story of a piece of chewing gum from a baseball player sold on eBay for hundreds of dollars, memorabilia serve as a personal link from a buyer to his heroes as well as speculative investment on the future value of the item. However, the authenticity of these items is often dubious. Some outlets create a certification process, even attempting to affix some sort a hologram or other identifying marker to the item. However, while possession may be "nine-tenths of the law," having some deed or other documented claim to an item would be incredibly valuable, as would the ability to track the chain of custody of the item. But trying to manage paper in the digital era seems like a fool's errand. Managing ownership and authorizing a transaction is what blockchain does very well. In the same way that it's used as a manager of supply chains in other industries, tracking the supply chain of memorabilia would facilitate the fact that these items often change hands over time. It's one thing to see a merchant selling an autographed limited-edition picture of Larry Bird and Magic Johnson and claim that it is authentic. It is another for him to provide digital proof that he is the owner and then formally transfer of ownership via blockchain so that he cannot attempt to resell a fake copy. The preservation of true value and reduction in fraud will have a profound impact on this industry.

3.4.1 Broadcast Content

One of the biggest revenue generators in sports is broadcast rights. Over the last 30–40 years, the content has become increasingly commoditized. In the 1970s, sports were limited to three networks in limited quantities. But with the explosion of cable/satellite TC and the proliferation of digital content over the internet, an infinite library of content was created, and broadcast is now generated every day. Yet, in this era of commoditization, sports have been able to generate a unique premium on their content because of live delivery or "appointment viewing." All major sports leagues have seized on this trend. Today, any person anywhere can access virtually any game from any major professional sports league. There's also an additional market for everything from statistics and highlights to commentary about the games. The concept of a 24-h news cycle by CNN and Fox News often overshadows the fact that sports have been on a 24-h cycle for years, particularly via talk radio; though sports broadcasting has now reached new heights with shows that take place at all hours on networks such as ESPN and Fox Sports. Personalities such as Steven A. Smith and Skip Bayless have greater profiles than many professional athletes, even though neither man has stepped on a field in their lives.

Currently, many leagues and networks offer subscription services to be able to monetize this content. However, as the content grows increasingly digital, the ability to manage everything from bundled subscriptions to micropayments for "pay as you go" content calls for a simple system of permissions and payments deliverable by blockchain. Whether it's payments or a cryptocurrency, rules that manage what content is viewable by what individual or the ability to track usage in a transparent way has value. In this context, smart contracts will be defined to confirm permissions and proper payment. If the smart contract is written properly, infinite permutations are possible on what content is received. Subscription by city, franchise, sport, league, or paying just for what you want to watch is all possible from a blockchain account. Increasingly, consumers are demanding flexibility and choice in their purchasing decisions. A 200 USD subscription to a satellite provider is now possible because managing micro-payment system for content would be extremely difficult. Even at a pay-per-view level, the purchase process and management of rights is difficult. But this is what consumers want—they want to pay only for what they watch and not be charged for what they don't. They want the flexibility to bundle when advantageous and unbundle when the aggregate value does not exceed the price they're willing to pay. While it is likely that this phenomenon will affect all forms of media, it is especially interesting in the world of sports when you consider some of the lesser-known sports that represent the long tail of viewership. While Badminton may not have the universal passion of football (soccer), there is undoubtedly a fanbase that would gladly pay for the digital content; easing the friction of this payment will increase consumption and potentially grow the sport.

4 Why This Won't Happen Today

These use cases represent only a subset of the ways that blockchain will be used to support professional and amateur sports. However, a number of these scenarios will take time to develop. The reason you won't see these scenarios manifest anytime soon, even though many likely will *eventually* happen, is a result of both the limitations of the technology as well as some of the limitations of the industry.

From a technology perspective, blockchain continues to improve as countless engineers look for new ways to boost its effectiveness. It's only 11 years old—compare that to cloud computing, artificial intelligence, or the internet of things, where the concept and some of the initial applications have been around for dozens of years. Blockchain is the infant of the next generation of technologies and the future of the internet and connected devices. As a result, there are still concerns; among them is the throughput of transactions, the latency of each individual transaction based on the resolution of the confirming nodes, and general liability. Given billions of dollars are contained within the bitcoin blockchain and there is been no hack of the system itself, the security of blockchain is unparalleled. For Ethereum blockchain, which features smart contracts, the security is a little more challenging and performance needs to be addressed. The founder of Ethereum, Vitalik Butterin, famously coined the term, "Vitalik's Trilemma." He said, "Decentralization, Security, and Performance. Choose two." If you want a decentralized network with enough confirming notes so that no one can exploit the system, you will suffer in performance. If you want to move faster but maintain decentralization, you risk rogue parties performing insecure transactions and threatening the security of the system. If you want speed and security, you need to sacrifice some of the decentralization and "trustless" nature of the system and accept a bit of an oligarchy—a concept that frightens most blockchain purists that believe that the system is only viable when it is truly democratized.

In the current iterations of systems such as bitcoin and Ethereum, performance is not tenable for mass consumption. However, much like "Moore's Law" works on microprocessors and the general evolution of hardware and software, these technologies tend to grow exponentially in performance and capabilities. The same is already happening for blockchain with side chains, "lightening networks," and new consensus algorithms—not to mention leveraging Moore's Law itself to create more powerful validators of transactions. But mass adoption won't happen overnight and there will need to be patience. And that's OK because the sports world isn't quite ready for a lot of the ideas proffered in this chapter.

The business of sports will be initially resistant to change, especially with the dramatic effects that a technology such as blockchain could have on it. Whether it's players' unions that are concerned about the micropayment nature of compensation for athletes, the broadcast networks that may not want to give the flexibility of payments to end-users, or simply the morass that is sports gambling that continues to bounce around our legal system, there will be resistance. Ultimately, consumer demand and the need to evolve will make many of these changes inevitable. And, when it does, the technology will be ready.

5 What About Even Further in the Future?

For a willing industry that can overcome its anxiety around the technology, most of these developments described above will happen in the next five to ten years, if not sooner. But looking further out, the crystal ball can get a little hazy in determining exactly what the impact of blockchain is. There's a number of reasons for this:

- Because blockchain is still in its infancy, some of the most important developments haven't happened yet. Unlike many of the other technologies in this book, the direction of blockchain is not locked in and will likely be impacted by the developments in each of the other fields that are being discussed.
- Many detractors of blockchain cite the potential impact of quantum computing and its astronomical increase in computing power as something that will render blockchain security measures obsolete. Blockchain relies on computing power to validate transactions and, if it is too easy, there is vulnerability in the system. While there's little doubt that the innovation of blockchain will manage to stay ahead of this, it does remind us that a new evolution of blockchain is inevitable and the foundation of the technology is likely to shift considerably in the years to come.
- As with most technologies over the long term, the impact of society's adoption of new behaviors will inevitably change the course of blockchain's impact. For example, it was impossible to predict a company like Uber without knowing the growth of mobile devices, GPS capabilities, and a social construct that allows us to interact more freely with strangers—undoubtedly created by the rise of social media. The new social norms and behaviors that develop over the next several years can impact the nature of the data stored in a blockchain as well as the value of the smart contract policies and permissions.

Nevertheless, the impending technological developments around increased mobile device connectivity and bandwidth, a greater reliance on the devices that we each carry (future phones or whatever will eventually replace them) as well as the devices that will likely be embedded in each object that we acquire, and the ability for all these devices to utilize unique private keys that enable secure transactions on the blockchain, will open the door to a lot of transformational changes even beyond the inevitable societal changes.

The most important revolutionary impact of blockchain, regardless of cryptocurrency or smart contracts, is that its ability to disintermediate transactions will reduce, if not eliminate, the need for central authorities. In sports, that central authority often creates friction that either slows or prevents competitions. For example, if you're running a fantasy football league, why not allow a smart contract to handle that? No need for Yahoo or ESPN. Everything from the computation of the statistics and associated scores, to the escrow and payout to the winner, it can all be managed by code. This has many more far-reaching ramifications.

The lines between amateur and professional sports will be blurred as the ability to ease the exchange of money and manage the rules around that transfer of money is a basis of competition. And now, that can all be done digitally with digital keys. Let's consider two examples:

5.1 "Amateur" Sports

Every day, tens of thousands of pickup basketball games get played around the world—at the gym, on playgrounds, at university fieldhouses, or even in private driveways. Amateur athletes elbow, shove, jump, and dive for little more than bragging rights. Trying to orchestrate a wager to "make things a little more interesting" isn't feasible; at least not feasible until blockchain reaches prominence.

Effective recordkeeping and the ability of smart contracts to handle escrow will turn a five-on-five pickup game at the gym into a way to play for cash, just as the organization of fantasy sports leagues have allowed. When the game starts, each player taps on a machine to submit their "entry fee." Last team standing splits the prize. The hoops are programmed to report scores, track the winners, and ultimately allow the primary smart contracts to manage impromptu tournaments. You can create a semipro set of leagues that forego the glitz and glamor of Lebron James for just people good enough to make a living. Seem crazy? Not at all. One hundred years ago, semipro baseball teams were quite common for players that were certainly talented, but not nearly good enough to play in the major leagues. There have been attempts to achieve that semipro status with basketball leagues now, including a three-on-three league founded by rapper Ice Cube that likely won't be able to muster sustainable commercial success. But as fantasy sports have shown, people are willing to bet on themselves. And blockchain's ability to manage these competitions and seamlessly (natively) integrate with a flexible cryptocurrency will make this all possible.

As with many technologies in sports, the trickle-down effect of what happens in the professional leagues will soon impact the amateur levels, but blockchain may actually provide a bigger bang for the buck with amateur players—and thereby create a new layer of sports competition and participation.

5.2 Tokenized Contracts

Of course, if we see the evolution of amateur sports, it only seems fitting that professional sports will change significantly in the way prize money payouts can go out. And because the fluidity of currency as well as the smart contract management as payments can be so seamless, many professional sports teams will turn into the equivalent of publicly traded commodities.

Technically, this is not without precedent. Most famously, the NFL's Green Bay Packers are held as a publicly owned nonprofit corporation. But these shares are clearly held as a novelty as opposed to a true financial instrument. Shareholders do not gain any true equity, there are no dividends, and the team does not fall under the protections of the SEC. Shareholders receive voting rights, an invitation to the corporation's annual meeting, and the bragging rights of being able to claim ownership of football's most-storied franchise. That's it. But any time the Packers need money, they can issue a "public offering" and raise money. This was done in the twenty-first century when the team needed to make major renovations to their legendary stadium. With a rare opportunity to buy into Packer "ownership," fans quickly jumped on the opportunity to heavily subsidize the renovations—certainly a boon for a team with a passionate fanbase, but not a realistic security that one purchases for portfolio optimization. With blockchain, it is going to make a lot more financial sense. Rather than buying into the business, fans can buy into their team's success by acquiring rights to cash flows from prize money. Shares can be managed on the blockchain with ownership defined by smart contracts and money being distributed via cryptocurrency.

Even in 2020, the seeds of this evolution are happening, though not in a meaningful or sustainable way. For example, Spencer Dinwiddle, a forward for the Brooklyn Nets of the NBA, is attempting to tokenize his future earnings on the blockchain. While there is certainly a lot of hype around this effort, as it does make an innovative use of the blockchain, there are many structural failures of this model that will kill it in the short term. In his case, he is attempting to take one year of his earnings (for the 2022 season) and make a speculative investment around it. Creating some financial instrument that serves as an annuity as a portion of future earnings can make sense, but the ephemeral careers of professional athletes could create issues. For example, in recent years, a number of NFL stars have announced retirement in their 20s, something that was unheard of a generation ago. Given the money earned in the early years of a career, increased concern around concussions that leave long-term effects, not to mention the pure punishment that's done to an NFL body, players are finding less and less reason to continue playing into their 30s.

But what if that player is bound to a tokenized contract?

There are interesting applications for this in a non-sports context, such as a Stanford Computer Science student that tokenizes his future earnings in exchange for tuition money. But, it gets sloppy when individual athletes are concerned. With teams, who are eternally incentivized on winning and whose existence is effectively into perpetuity, however, the investment makes sense. And that would be the case for professional sports franchises. One day, portfolio managers will look to sell sales of General Motors and put that money into the New England Patriots.

6 Summary

The blockchain's role as a disruptive technology in the FinTech industry makes it a perfect fit for the future of sports, particularly as it relates to sports as a business. Anywhere transactions between multiple parties occur or privileged management of data exists, blockchain will become the de facto solution and allow the evolution of these use cases to create new business models. Whether it's bringing a level of professionalism to amateur sports or democratizing professional sports for the inclusion of amateur owners/fans, blockchain will reduce friction and increase the pace of innovation. While the short-term benefits will be limited by the willingness of the incumbents to accept some of these drastic changes, the long-term future of sports will be profoundly impacted by blockchain.

Sandy Khaund is Vice President of Product at Ticketmaster. Sandy joined Ticketmaster as part of the acquisition of UPGRADED, a Blockchain ticketing company he founded that worked with clients from MLB, the NBA, and motor racing events. Sandy has a long history with sports properties, which includes his time at Turner Broadcasting and as CTO at InStadium. Sandy's professional love of sports is only exceeded by his personal love of sports, which includes playing in multiple softball leagues and logging over 10,000 miles on his Nike+ running app. Having started one of the first Blockchain ticketing companies, Sandy has seen the growth of Blockchain technologies and believes its transformational impact on sports will far exceed the world of ticketing.

Blockchain, Sport, and Navigating the Sportstech Dilemma

Martin Carlsson-Wall and Brianna Newland

> *It's sad to see those old guys in there. In ten years, I am sure they will still be here lobbying and voting. However, I don't think they will understand why their sport lost relevance and became smaller. I don't have time to wait. I need the action now!.*
>
> *—CFO, The SPOT, May 16th, 2018.*

Abstract

In their chapter, Carlsson-Wall and Newland introduce the *sportstech dilemma*. They describe how sport is an industry driven by emotion and the importance of maintaining competitive balance, which distinguishes it from other industries. Then, they survey the blockchain tech landscape in sport and differentiate seven market segments depending on customer type and the type of impact sought. They propose three strategic questions—concerning the level of integration into the sport ecosystem, potential for a hybrid business model, and geographic footprint—to guide companies navigating the sportstech dilemma. Finally, they look further into the future and see unexpected possibilities for blockchain in sport.

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This quote, recorded outside the SwissTech Convention Center in Lausanne, captured the frustration of the tech industry with sport leaders. Even though Lausanne is a small city of about 140,000 people, it is seen by many as the capital of the sport world because the International Olympic Committee (IOC) and about 30 International Sport Federations have their headquarters there. As a consequence, few places can muster as many networking opportunities as Lausanne. However, after two days of mingling with sport leaders, the Chief Financial Officer (CFO) was disappointed. The sport and tech industries seem to operate with very different logics. Why was this so? Why were the older gentlemen from the sport federations not seeing the innovation opportunities?

At first glance, sportstech is a great combination because it combines two big sectors in society. Regardless of occupation or age, most people like to follow a sport team, or discuss the latest technical apps on their iPhone. Surprisingly, however, many tech start-ups struggle to navigate the sport industry landscape. As a seasoned venture capitalist in Silicon Valley posited to one of the authors—why would you invest in sportstech when sport is one of the most conservative industries in the world? This tension—that sport wants to preserve traditional history, while tech wants to disrupt that history—is at the core of this chapter. We call this the *sportstech dilemma.*

In this chapter, we will do three things: First, we will describe how sport is an industry driven by emotion and the importance of maintaining competitive balance (Stewart & Smith, 1999; Smith & Stewart, 2010). The potential and desire for innovation does not mean that one player or team wins all the time. In this way, the sport world is different to many other industries where individual competitive advantage is something positive (Stewart & Smith, 1999). Secondly, we will survey the emerging blockchain landscape. With the generous help of the company SportTechX and various industry reports, we identified 63 blockchain companies with solutions for the sport industry. We divided them into seven market segments and created a model that shows how the companies differ depending on customer interface (Anderson, Håkansson, & Johanson, 1994) and the type of impact they want to create in the sport world. Finally, we will propose three strategic questions for navigating the sportstech dilemma. These rely on the level of integration with the existing sport ecosystem, the type of business model one applies, and the importance of having a (inter)national ecosystem supporting blockchain initiatives.

1 The Sport World—the Importance of Emotions and Competitive Balance

Regardless if one analyses Formula 1, soccer, or track and field, maintaining the competitive balance is a critical issue. It does not matter if it is an equipment sport, a team sport, or an individual sport, the commercial success is intimately tied to the fact that everyone has a chance to win (Smith & Stewart, 2010). For example, imagine a betting company with no uncertainty—there would be no product.

Similarly, uncertainty and spontaneity drive interest in sport spectating. Why would fans watch a Formula 1 race if they know the outcome from the start? Fans lose interest when sport becomes predictable.

However, the process of achieving competitive balance is far from easy (Stewart & Smith, 1999). It requires making decisions on how the game is played, what equipment is allowed, and the order for how games or events are scheduled. In many sport, transparent democratic processes are crucial for achieving competitive balance. Take for example, the Olympic Games, one of the largest events in the world. In order to get all National Olympic Committees to collaborate, there is a need for a fair system with long-term stability. Athletes train and prepare for the Olympic Games for many years. If new innovations are suddenly allowed and unfavorable conditions are created where only one or two athletes could potentially win, the credibility of the entire system is destroyed.

Figure 1 illustrates how the global ecosystem within sport is made up of public, private, and non-profit organizations. The system is run by many non-profit organizations that are totally dependent on private sector organizations to sponsor and pay for media rights as well as national and local public organizations that fund the training facilities. Understanding this system complexity is crucial for navigating the sportstech dilemma. A blockchain company in sport has to understand that (1) the sport world is designed for long-term stability and (2) a technical solution can become quickly obsolete if a competitor succeeds in becoming the global standard.

What about North America, you might ask? Are professional sport leagues such as the National Football League (NFL), the National Basketball Association (NBA), Major League Baseball (MLB), and the National Hockey League (NHL) not more

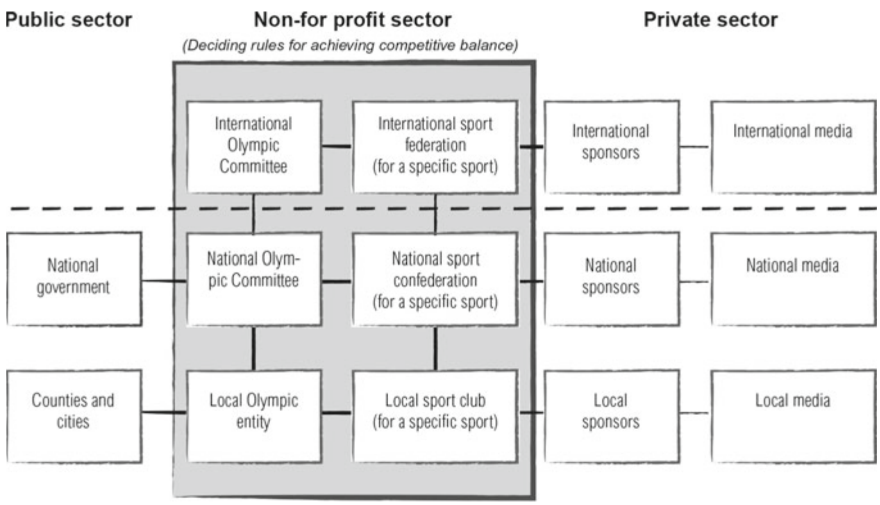

Fig. 1 Simplified illustration of the global sport system

commercial? Yes, they are. However, commercial leagues also need to maintain competitive balance. The draft system, salary caps, and game schedules are carefully crafted to ensure that any team can win. Thus, integrating a new technology like blockchain is a complex endeavor even though it occurs in a commercially driven sport.

2 The Emerging Blockchain Landscape Within Sport—Main Categories

Blockchain is a technology with many opportunities. Analyzing sportstech start-ups, the global auditing firm PwC found that blockchain use in sport has four main features: it is decentralized, shared, transparent, and secure.[1] *Decentralization* is key because no one owns the ledger thereby cutting out third parties and saving the user money. With *sharing*, each member has a copy of the ledger that is synched with the system and anyone can review the history of the ledger, providing *transparency*. Finally, blockchain provides *security* because every transaction is validated, coded, and recorded in the ledger. The ethical implications are critical for sport organizations as consumers' personal data is better protected and key organizational information is clearly documented, trackable, and resistant to security breaches. Because of this, stakeholder engagement can be improved, costs can be reduced, and personal data can be handled with more security and transparency (Table 1).

2.1 Sport Betting—18 Companies

The sport betting category is the largest market segment with 18 companies. Because sportsbooks have so much money on the line, all stakeholders benefit from a permanent and verifiable record of the transaction ledger. Gamblers can verify pay-outs and sportsbooks cannot claim that the system generated incorrect odds that cannot be fulfilled because blockchain ensures transparency.

Companies who are leading development in this area are Bethereum.com, 1XBit.com, Decent.bet, and Betr.org. Since blockchain eliminates the middleman, many of these companies emphasize how they want to revolutionize the betting market. With lower fees, more money is given back to the customers; but companies also stress how gamification and social elements can make the experience more fun and interesting. As an example, Decent.bet describes in their white paper how existing players will be challenged by new entrepreneurs:

[1]See report by PwC called "How blockchain and its applications can help grow the sport industry?". It is part of Ambitions 2024, an initiative to develop innovative solutions for the 2024 Paris Summer Olympics.

Table 1 Companies and market segments of the emerging blockchain and sport landscape

Sports betting
- 1XBit
- Betdemocracy
- Bethereum
- Bitplay
- Blinkpool
- BlitzPredict
- Blok Sports
- Decent.bet
- FansUnite
- Fantasy Sports Betting
- Herocoin
- My Ether Sports
- Pay2Play
- Ryu Games
- Stox
- Unikoingold
- Wagerr
- ZenSports

Fantasy sport
- Digital Fantasy Sports
- FNTC Sports
- FootballCoin
- No Limit Coin
- Pokersports
- Protoblock
- Rankingball
- Strykz

Club and league management
- Bandwagon
- Blocksport
- Chiliz/Socios.com
- Dapper Labs
- Fantastec
- Football Fan App
- Footies
- Instant Sponsor
- StarGraph
- Tixico
- United Fans
- WisFans

Health and personal integrity
- Lympo
- PeersPoint
- PlayMaker Chain
- Revvo
- Spobi
- Sweatcoin

Ecosystem development
- Beat
- Cryptosport
- Mediar
- Olympia
- Plair
- Ronaldinho Soccer Coin
- Setteo
- Sportcash One
- Tookens
- Womprotocol

Collectibles and memorabilia
- Animoca Brands
- Ex Sports Starz
- Gamedex
- Pro Exp Media
- Stryking

Talent investment and crowdfunding
- Globatalent
- Jetcoin
- Netscouters
- SportyCo

> The gaming industry itself is like a dinosaur. It's old. It's lumbering. It hasn't evolved. While the industry looks at existing trends like Esports, AR and VR and tries to figure out how to "gamify" it—the reality is, the future of gambling isn't going to come from some publicly traded conglomerate with shareholders to answer to every earnings report. No, the future of gaming is going to come out of nowhere… It's in the mind of some latent genius in his or her basement.
>
> (DECENT.bet white paper, April 2019)

In this category, there are betting companies that focus on a specific niche. For example, Blinkpool and Herocoin focus primarily on esports with games such as Dota 2, League of Legends and CS:Go, while Bitplay uses blockchain for lottery options.

2.2 Club and League Management—12 Companies

The second largest market segment is club and league management with 12 companies. In this segment are companies who sell to clubs and leagues and want to support the current way of working within sport. In that sense, they are very different from many betting companies who want to revolutionize and disrupt the sport world.

A good example in this market segment is Chiliz.com/Socios.com. Based in Malta, the company focuses on soccer and esports; they want to help clubs improve their fan experience. Working with Juventus, Paris Saint-Germain, Atletico Madrid, West Ham, and Roma, Chiliz.com/Socios.com help clubs sell fan tokens to supporters. The more tokens one owns, the more influence one can have on the decisions open for supporters to vote on. Another initiative is NBA Top Shot, a new partnership (announced July 31th, 2019) between the NBA and Dapper Labs, which aims to create digital collectibles. Rather than being a competitor to the league, Dapper Labs provides a technical solution that enables the NBA to better leverage fan relationships. Over time, their ambition is to include the digital collectibles into various gaming solutions so that the NBA can create new ways to increase revenues while strengthening the fan experience.

Another company that has chosen to partner with the existing ecosystem is Blocksport.io from Switzerland. Focusing on clubs, leagues, and federations, they provide a technical solution that integrates several features such as ticketing, voting, loyalty programs, and merchandising. By providing a holistic solution, the ambition of Blocksport.io is to be a "one-stop-shop" whereby clubs can bring both fans and corporate sponsors closer to them. Fantastec.io, a company that sells to clubs and leagues, works with Real Madrid, Arsenal, and Borussia Dortmund to create better fan experiences through artificial intelligence (AI), virtual reality (VR), and blockchain. Footies.com helps Maccabi Haifa from Israel with online ticketing, and WisFans.com developed "a digital clubhouse" together with FC Barcelona and Team Oracle (sailing).

2.3 Ecosystem Development—10 Companies

The third largest market segment, with 10 companies, is "Ecosystem development." We chose this name because blockchain start-ups in this market segment want to create a larger ecosystem of collaborative companies. In some cases, they support existing ecosystems within a sport. In other cases, they want to create totally new ecosystems. An example is the German consortium Beat.org. Focusing on personal health, individuals share their sport data and get rewarded. Having a strong presence in the German fitness industry, the lead company MySports GmbH integrates technical solutions from many different companies.

Another initiative is Olympia.io. Focusing on amateur sport, their vision is to create a universal database for amateur sport and physical activity. Under the slogan, "Olympia—decentralized sport ecosystem," the project wants to integrate sport applications, institutions, businesses, and players. Through blockchain technology, the vision is that each individual will have his or her personal identity on the Olympia platform and that individuals will get rewarded for sharing information or interacting with sport clubs, government organizations, and businesses.

Similar to sport betting, there are ecosystems that focus on particular niches. For example, setteo.com has a strong position within racket sport; Sportcash.one, with its heritage in Brazil, was early into surfing; and Plair.life aims to create an ecosystem for gamers.

With the high costs of starting new ecosystems, there are start-ups who seem to have lost momentum. One example is the Ronaldinho Soccer Coin Project. Formally announced in June 2018, the project has experienced several delays. On the formal website, www.soccercoin.eu, the latest news from October 2019 reads, "Notification of communication failure. The connection of 'https://tokensale.soccercoin.eu' is now very unstable. We are currently working on recovery."

2.4 Fantasy Sport—8 Companies

Like sport betting, fantasy sport is a market segment that is concerned with transparency and security and has a strong North American presence. For example, Digitalfantasysports.com employs a blockchain platform to connect global players, provides social opportunities through live chats, and uses tokens for fantasy play. The site also offers opportunities to engage in global fantasy play and offers private tournaments. PokerSports.com is unique in that it uses gamification to engage players. Its program, called Fantasy Stud, deals seven player cards face down on a poker table; the cards are revealed during betting rounds to reveal the user's fantasy team. Like the other companies, PokerSports.com uses tokens, a decentralized platform, and transparency. Finally, the European fantasy sport company, Footballcoin.io, focuses on soccer and integrates blockchain with the popular Football Manager game genre. This fantasy game allows players to showcase their managerial skills by giving them a platform to create the perfect football team.

2.5 Health and Personal Integrity—6 Companies

A fifth market segment is concerned with health and personal integrity. In this category, blockchain companies focus on both elite athletes and the general public. With the innovation of wearable technology, coaches and athletes can get real-time biometric data that can complement performance statistics. Focusing on the elite athlete, Peerspoint.com uses blockchain to compare individual players, identify young talent with a high probability for excelling, and identify players undervalued in the market. Further, Peerspoint.com can monitor player movements and physical performance during training and games to predict injuries as well as provide feedback for injury recovery plans. Finally, the technology can identify patterns that influence strength and weakness in performance.

Two companies that have similar business models are Lympo.com and Sweatcoin (www.sweatco.in). Both companies focus on the general public; by collecting health data, they have created reward systems for individuals and companies. Lympo has the slogan "walk, run, earn," while Sweatcoin uses the slogan "it pays to walk." The Sweatcoin app became very popular on the iTunes App Store. It ranked 22nd as of January 2020 with over 400,000 downloads worldwide (Sensor Tower 2020). The app even inspired a 2019 academic article published in the British Journal of Sport Medicine.

2.6 Collectibles and Memorabilia—5 Companies

The sport collectables industry is wrought with fraud. Items are often fake, and it is difficult to verify authenticity. Here, one can see clear potential for blockchain technology, given the transparency it offers companies and buyers. We have identified five companies within this market segment. Using a B2B model, the Vancouver-based company, Pro Exp Media (www.proexp.net), has formed a partnership with the NHL team, the LA Kings. The augmented reality (AR) blockchain platform will ensure 100% authenticity of all merchandise bought online from LA Kings, thereby enhancing the fan experience.

Three other companies in this segment are Animocabrands.com from Hong Kong, Stryking.io from Germany, and EX Sport in Singapore and Bangkok. Animocabrands.com has a strong presence in Asia and works with Formula 1. The German-based Stryking.io focuses primarily on German soccer and has a formal partnership with Bayern München. In 2019, Stryking.io was acquired by Animocabrands.com. EX Sports (www.ex-sports.io) focuses on martial arts with partnerships with Jiu Jitsu and Muaythai federations. Within both sport, EX Sports' ambition is to increase revenues for both federations and individual athletes through digital collectibles.

2.7 Talent Investment and Crowdfunding—4 Companies

The final market segment concerns talent investment and crowdfunding. For background, many athletes do not know if they can fund their sport careers. Their personal or family resources might not be enough to continue training and competing or they might participate in a sport where only specific positions make a lot of money. Several blockchain companies have emerged to help athletes finance their careers. For example, at TokenStars.com, fans can buy tokens to support athletes, participate in auctions, and even scout new talent. Other companies like Sportyco.io use the Sportify (SPF) token to fund talent. Investors who contribute tokens to an athlete's fund receive a share of the athlete's future earnings as their return. Globaltalent.com allows fans to buy and exchange tokens in order to gain access to their favorite teams and/or athletes. Athletes can raise funds to develop their careers, later giving fans back a portion of their income; while clubs and sport organization can raise funds in exchange for a percentage of tickets, sponsorship, television rights, and more.

In order to summarize the current state of the blockchain and sport landscape, we have created a simple matrix illustrated in Fig. 2. The matrix is based on research that shows that a company's strategy can be distinguished based on the type of customer they are serving (Anderson et al., 1994; Zander & Zander, 2005) or if they want to support or disrupt the market they are entering (Baraldi & Strömsten, 2009;

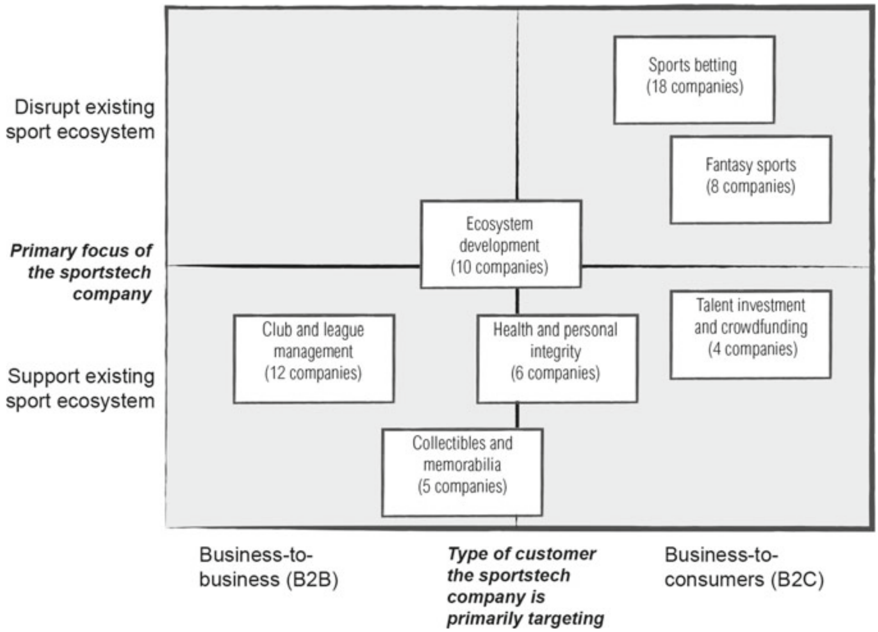

Fig. 2 The emerging blockchain and sport landscape

Garud, Kumaraswamy, & Karnöe, 2010). Starting in the upper right quadrant, we have the largest segment, sport betting with 18 companies. As we described, this is a segment, with several companies from the United States, focuses on disrupting the market. On the contrary, the club and league management, with 12 companies, focuses primarily on supporting the existing ecosystem by forming strong business-to-business relationships. In this market segment, many blockchain companies have stronger foothold in Europe. In between these two extremes, we have the other five segments. Given that this is an emerging market, we want to emphasize that boundaries between segments are blurred and that individual company can often be situated in more than one category. As a consequence, we see Fig. 2 as a start to structure the blockchain and sport landscape to create discussions about future opportunities and how companies can manage the sportstech dilemma.

3 Strategic Questions for Navigating the Sportstech Dilemma

As noted in the introduction, blockchain companies have to navigate the sportstech dilemma, which is defined by sport's notoriously slow response to change. As the start-up CFO said, "I don't have time to wait. I need the action now!" In this final section, we outline three strategic questions that blockchain companies could use to guide them in formulating their long-term plans.

3.1 Strategic Question 1: How Much Integration with the Existing Ecosystem Is Needed?

A first strategic question is to determine how much integration is needed with the existing sport ecosystem. One challenge is that the tech industry might not have a clear understanding of the complexities of the sport ecosystem. Especially in the context of the highly complex—and perhaps even chaotic—United States, for example. As we have indicated, some integration is necessary. The question is, how much? There are a number of tactics that could be capitalized on between two extremes. On one hand, imagine a tech company that has a very good relationship with key decision makers in the International Olympic Committee or in an international sport federation. Knowing the political twists and turns, this tech company could try to establish itself as the global standard within one or several sport. In Fig. 2, this would be a company in the lower left quadrant (B2B customers, support existing ecosystem). On the other hand, imagine a company that understands the sport system's complexity (and deep-rooted historical politics) and so tries to avoid all together. Realizing that there are limited lobbying resources, the second tech company might find it wise to focus on a business-to-consumer solution where global standards are not as important. A review of the current blockchain landscape, we see examples of both strategies. Some companies such as Chiliz.com/Socios.

com, Dapper Labs, and EX Sports work very closely with existing clubs, leagues, and federations. On the other extreme, sport betting companies like Decent.bet discuss sport organizations as "dinosaurs" and try to position themselves as innovative disruptors, which in Fig. 2 is in the upper right quadrant.

The degree of integration is important to monitor over time. A "low-integration strategy" may function in the beginning, but what happens as the tech company grows? For example, it might be that Chiliz.com/Socios.com is successful now, but will they be able to continue to grow? In a commercial and free market-driven environment like the United States, operating outside the sport ecosystem could be viable. There are plenty of sport organizations across youth, school, amateur/recreational, and professional sport that many tech companies could sustain business and grow. However, in a smaller, more closed system like many countries in Europe, what happens if there is a global standard tech company option chosen across many sport? In this case, integration within the existing sport ecosystem becomes a more constant strategic issue that needs to be closely monitored and re-evaluated. Therefore, to succeed in countries and their associated sport ecosystems, tech companies will need to have a strong understanding of the sport industry to be able to capitalize on opportunity.

3.2 Strategic Question 2: Is It Time for a Hybrid Business Model?

A second strategic question can be seen as a continuation of the first, because the sportstech dilemma is difficult to navigate, is there risk or opportunity associated with developing a corporate identity focused solely on sport? Is it better to create a company that can reach other parallel customer segments? Imagine, for example, a blockchain company creating a member voting solution. This tech company could certainly sell its solution to global sport organizations and clubs. There is a clear benefit of having membership clubs, like FC Barcelona, use a voting solution. Instead of branding itself as a sportstech company, however, an alternative strategy would be to consider a "hybrid business model" in order to target industry segments outside of sport. For example, a company with a smart voting solution, could target political parties, municipalities, and unions, which also need solutions to revitalize democratic processes. The entertainment business could also make use of voting solutions for TV shows or major industry award shows like The People's Choice Awards in the United States. Of course, this hybrid business model carries the risk that the company loses its distinct sportstech identity, but in order to avoid the pitfalls of the sportstech dilemma, this could open the door to broader opportunity outside the scope of sport. Having a broader customer portfolio could help to leverage the positive brand connections within sport while gaining more predictable and less demanding customers from other segments. And, given the entertainment and sport industries have a symbiotic relationship, broadening into entertainment might strengthen links to sport. One company that appears to have a hybrid business model is Animocabrands.com, which not only has strong sport relationships with Formula 1 and German football (after the acquisition of Stryking.io), they also sell products to non-sport customers, which includes the entertainment industry. Another hybrid twist is to use sport as a branding opportunity like Wisfans.com. The owner of Wisfans is the Swiss company, Wisekey.com. Wisekey sells solutions in blockchain, AI, and internet of things (IoT) to governments, automotive industry, and luxury brands.

Hybrid models provide protection from risk of the sportstech dilemma when sport organizations are averse to change or too slow to adopt new tech solutions. Branching into other industries could also provide leverage when pitching to sport organizations by providing strong evidence that the solutions work.

3.3 Strategic Question 3: How Much (Inter)National Support Is Needed for Blockchain to Succeed?

A final strategic question concerns geographical footprint. Where should the company set up its office(s) to best attract customers? With the technical complexity of blockchain, it could be worth considering if national and/or international support is required for blockchain solutions to succeed. For example, will big blockchain sportstech companies from a country where there is no national support from policy makers and/or universities flourish or die? Two interesting cases are from Switzerland and China. Switzerland, with its strong blockchain heritage, has created collaborative forums such as the Crypto Valley (www.cryptovalley.swiss) and Trust Square (www.trustsquare.ch) where universities, companies, public organizations, and not-for-profit organizations meet and collaborate. With "the capital of the sport world" in Lausanne, interesting opportunities for further development could flourish well. Likewise, in China, President Xi Jinping has continuously stressed the strategic importance of being a leading blockchain nation. Most recently, in October 2019, President Xi re-affirmed his belief and said that China should continue to invest in basic research and in industries such as customs, healthcare, and banking. With the Olympic Winter Games in Beijing in 2022 (and having hosted the Summer Olympic Games in 2008), China is now transforming into one of the most interesting sport markets in the world. With a combined interest in blockchain and sports, will countries such as Switzerland and China have a strategic advantage and form innovative blockchain clusters or will we see future winners from all over the world? And further, if such countries gain a foothold in not only sport but other key industries, will that motivate other countries to adopt similar solutions to remain competitive in the global marketplace? Dominant sport countries like China, Russia, and the United States are always seeking competitive advantage in not only sport, but other industries as well. Being left behind is not an option. The question is, will a national approach for integrating blockchain solutions actually motivate an international approach as an outcome? Only the future will tell.

4 The Crystal Ball: What Will Happen in 20 Years?

Although it is nearly impossible to predict where technological advancements will be in 20 years, we can attempt to make a couple of predictions. First, the pace of technological innovation has increased exponentially over the past 100 years. The telephone took 75 years to reach 50 million users, but only four years for the internet, two years for Facebook, and 19 days for the popular game PokemonGo to reach the same number. With 5G technology on the brink, high-definition (HD) downloads that take hours on 4G LTE will take seconds on a 5G network. This will have major implications for VR, which consumes 1 GB of data in one minute as well as the MIoT, which refers to the billions of devices and machines that require continuous connectivity. Sport venues could certainly capitalize on this innovation given its importance to the fan experience. Blockchain technology will be critical for these advances as companies will require security and transparency at warp speed.

Second, with advent of 5G, sport organizations can better incorporate AR, VR, and AI into the fan experience; and, again, this can be supported with blockchain solutions that enable decentralization and cost saving by cutting out the middleman. And, as with other blockchain solutions, it offers security and transparency allowing for cost-savings for the fan and sport organization. Again, the ethical implications this offers sport organizations are immense as they will be better able to protect consumer data from security breaches.

While sport organizations can take advantage of blockchain solutions with the introduction of 5G, the truth is it is difficult to predict the next 20 years for technology innovation given how quickly it changes in the present. One thing, though, is certain: with the need for long-term tech company stability, understanding and navigating the sportstech dilemma will be required of not only start-up CFOs, like the one introduced at the beginning of the chapter, but for many other individuals and companies interested in developing solutions for the sport industry. While it is certain that technology innovation will continue to evolve quickly and dynamically, the sport industry will likely adhere to its traditional ways. Therefore, the challenge for tech companies is to remain steadfast in their influence to encourage and educate sport organizations on the importance of the adoption of these technologies for their business. And sport organizations need to be open to these innovative solutions in order to remain relevant and enhance competitive advantage.

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The Rise of Emotion AI: Decoding Flow Experiences in Sports

Michael Bartl and Johann Füller

Abstract

In this chapter, Bartl and Füller explore Emotion artificial intelligence (AI), which has the potential not only to radically change the way sports are coached, but also how they are experienced and consumed. Their chapter illustrates how affective states can be measured with the help of AI and how the provided analytics may impact the sports experience. Besides giving insights in the role emotions play in sports, the empirical case study shows how to measure the state of flow of biathlon athletes with AI. Their findings show that the analysis of psychophysiological patterns allows classification of athletes' flow states and prediction of performance. And finally, they outline how Emotion AI may add value to the sports activity of athletes, coaches, spectators, and researchers.

1 Introduction

Digital technologies fundamentally change the way we train and do sports. They allow ubiquitous collection of structured and unstructured data that help us to run comprehensive data analyses and learn from exact feedback and precise simulations. Digital technologies boost sports performance by measuring and interpreting data—e.g., fitness, tactical, technical, and mental data—at an individual as well as team level. Although studies have shown that 70–85% of sports performance is

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determined by the mental state and psychological condition of the athlete (Raglin 2001), so far it is rather hard to measure emotions and affective state. Moreover, while sports analytics is a fast growing and multi-billion-dollar business (Link 2018), the measurement of emotions and psychological conditions such as stress, arousal, flow, anxiety, tension, or aggression has been rather neglected (Bali 2015). Thus, our understanding of the mental state of athletes, the influencing conditions, the mechanisms and influence on the performance, as well as the consequences for the physical and psychological health are still rather unexplored.

With this research, we shed light on the role emotions may play in sports and introduce an artificial intelligence (AI)-based method to measure and analyze athletes' emotions. We illustrate the AI-based method through findings of the "TAWNY Deep Flow" project, where we aimed to measure the flow state of athletes' in general and particularly of biathletes and its influence on their shooting performance. Our study shows that AI-based emotion recognition methods allow for classification of specific physiological patterns of the athletes, which help to predict their shooting performance. Based on our case study results, we discuss feasible scenarios to apply Emotion AI technology; we also discuss its potential impact on how we train and do sports and how we may experience and consume it in the future.

In this chapter, we use the term Emotion AI in the broader sense as AI-based technology that helps to detect complex human states in the sports context. These human states are predominantly of emotional nature (e.g., basic emotions) but can also cover cognitive dimensions and mental functions such as concentration or being in "the zone" known from flow theory. Both the affective and mental states are part of psychological processes, which are used for the recognition algorithms in Emotion AI.

2 Advances in Emotion AI

Human emotions play a fundamental role in social sciences, politics, business sciences, medical sciences, and sports. The fundamental problem for all scientific disciplines alike is a valid and reliable measurement of emotions. Currently, self-assessments-questionnaires, observations, and equipment-intensive lab-settings are used to detect emotions. A strong measurement bias is inherent to all these procedures. AI and deep learning open up a completely new and fascinating playground for new techniques to detect and classify emotions. With AI, measurements are much faster (or even instantaneous), less biased, location-independent, and possible at a larger scale when compared to traditional ways of emotion measurement. Accelerated by the advances in face detection and the analysis of voice and physiological data, these technological developments drive the emotion analytics market, which is growing with tremendous speed.

Affective computing is the scientific field dedicated to the detection of human emotional states. It is the study and development of systems and devices that can recognize, interpret, process, and simulate human affects. The aim is to allow machines or connected systems to interpret the emotional state of humans, adapt their behavior according to those states, and give an appropriate response for the given emotions (Picard 1997; Bartl 2018). In a first step, human data from facial expressions, voice, or biometric data from wearable sensors like heart rate variability (HRV), heart rate (HR), electrodermal activity of the skin (EDA), skin temperature, photoplethysmography (blood volume pulse), motion (accelerometer, gyroscope) are collected. In a second step, powerful neural networks and deep learning procedures are applied to explore interrelations between physiological data and psychological states with the aim to eventually classify human conditions like basic emotions (e.g., anger, disgust, fear, happiness, sadness, and surprise), stress, attention, productivity levels, and psychophysiological states. The classification of human affects is supported by inventories, scales, and tests from psychophysiological and social science such as the Positive and Negative Affect Schedule (PANAS) (Watson et al. 1988), the Oxford happiness inventory (Hills and Argyle 2002), the flow construct (Csikszentmihalyi 1990), and many others.

The demand for emotion recognition technologies pulls from various domains and industries. R&D departments intend to create smart and emotionally intelligent products (Bartl et al. 2017; Richter and Bartl 2018); human resources try to create safe and productive workplace improvements; sales teams try to optimize customer service (e.g., chatbots, call centers, recommender systems); production teams strive to minimize human failures at the assembly line; market research teams are eager to improve emotion measurement techniques; and start-ups want an easy way to test user experience of brand-new digital applications. In sports, emotion recognition has the potential to change the way athletes improve performance and how spectators experience the actions of their adored sports heroes. Generally speaking, recognizing human emotion is a key dimension to design breakthrough innovations that makes the world safer, healthier, more comfortable, and more productive.

3 Measuring Flow

Driven by advances in Emotion AI, the "TAWNY Deep Flow" research project is dedicated to determining if human flow states can be detected in an automated way (Maier et al. 2019). This idea goes beyond current efforts in emotion research to classify either the basic emotions (e.g., from facial recognition) or human affective states within the two-dimensional arousal-valence space. Valence is the positive or negative affectivity, whereas arousal measures how calming or exciting the condition is.

Flow is the mental state in which a person performs an activity with energized focus, full involvement, and enjoyment in the process. In this "optimal experience," one gets to a level of high gratification (Csikszentmihalyi 1990). The flow theory has been widely recognized throughout history and across cultures and by various research fields like psychology, marketing, and sports. The renowned Professor Mihály Csíkszentmihályi has driven flow research in sports for more than 40 years (Csikszentmihalyi 1990, 1992). In their book *Flow in Sports: The Keys to Optimal Experiences and Performances* (1999), Jackson and Csíkszentmihályi investigated factors that influence whether or not flow occurred during an athlete's performance. Some drivers of flow, according to their model, are the level of motivation toward the performance, physical preparation and readiness, confidence, and focus; some combination of which lead to the optimal experience often described as "playing in the zone" or "feeling on a high." So far, in-depth information about the experience of flow has largely been obtained through interviews or self-report questionnaires, known as the experience sampling method. Typically, self-report questionnaires are answered during or after performing a task. Critics of this approach suggest that it distracts flow, is inaccurate and time-intensive, and cannot be scaled in real-life scenarios. The TAWNY research project tries to overcome some of the limitations of traditional measurement techniques by developing an automated and real-time recognition of human flow states based on physiological data such as heart rate, heart rate variability, and electrodermal activity.

In a recent TAWNY research study, Maier et al. (2019) propose a method to automatically measure flow using physiological signals from wrist-worn devices. The method is the first attempt to apply end-to-end deep learning for flow classification based on a convolutional neural network (CNN) architecture. The model not only allows for recognizing high and low flow, but also allows estimation of whether the user is under- or overchallenged (i.e., bored or stressed) when not experiencing flow. For data collection, a custom version of the mobile game Tetris was created, which has been shown in psychological studies to lead to different affective states like boredom, stress, and flow (Keller 2011; Harmat 2015). The "easy" level was designed to lead to boredom, the "normal" level allowed for smooth playing and inducing flow, and the "hard" level led to stress. While playing, the participants were equipped with an Empatica E4 wrist-worn device, which captures physiological signals such as HR, HRV (based on blood volume pulse (BVP)), electrodermal activity of the skin (EDA), and skin temperature. Figure 1 gives an overview of the study.

With the collected data, it was possible to create a first-of-its-kind machine learning model that distinguishes three states: boredom, flow, and stress. Mean validation accuracies of 57, 70 and 71%, for boredom, flow and stress states, respectively, were obtained. It was found that during identified flow periods, the player performs significantly better than in boredom or stress periods. Consequently, the game can be adapted dynamically to a player's state thereby increasing performance and reducing stress. In a follow-up study with a similar setting and larger number of participants, TAWNY classified low and high flow states at similar rates and further refined the deep learning model (Maier et al. 2019). The study opened up new ways for empirically studying flow and making flow a more accessible psychological concept particularly for sports applications.

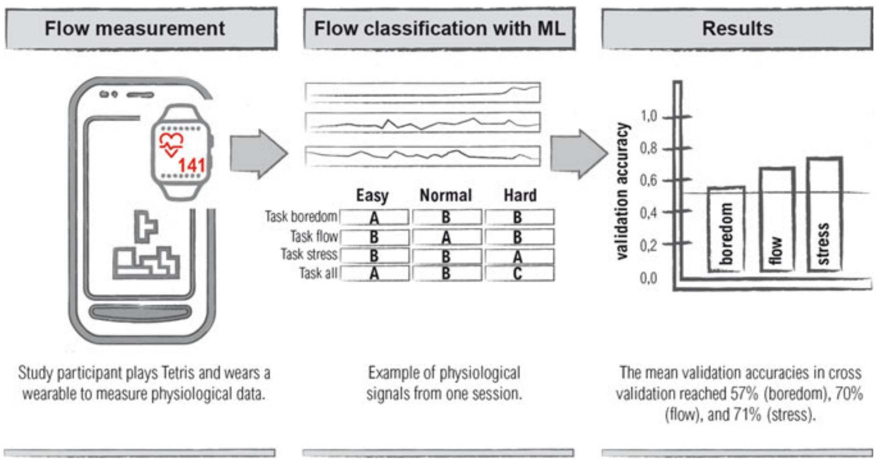

Fig. 1 Study overview for measuring flow (Maier et al. 2019)

4 The Biathlon Flow Study

Pursuing the vision of the TAWNY Deep Flow research project to decode the DNA of flow experiences based on human biometrics and AI, we conducted an exploratory study together with biathlon professionals and Red Bull Media House, the production and media company of the Red Bull corporate group. The primary questions that motivated us to conduct the study were the following:

- What kind of physiological patterns can be observed during shooting performance?
- Is it possible to classify patterns and states of flow performance—overload, fear, underload, boredom, and control—that differentiate hits from misses?
- How can AI-driven data analytics in the context of sports be processed as metacontent in media?

The study was conducted with four male junior professional biathlon athletes of team Switzerland, with an average age of 18.5, coached by former Olympic and world champion Michi Greis. The test track was at Lenzerheide in Switzerland. The study design is illustrated in Fig. 2.

For the measurement of bio signals during two training days, the wristband Empatica 4 and the Microsoft Band 2, as consumer friendly products, were used to collect data such as heart rate, heart rate variability, galvanic skin response, temperature, movement, etc. Additionally, the athletes were equipped with control devices like the Polar H10 breast belt. Cameras documented the shooting results of 100 shots fired within 70 min of training in competition mode. Afterwards, the

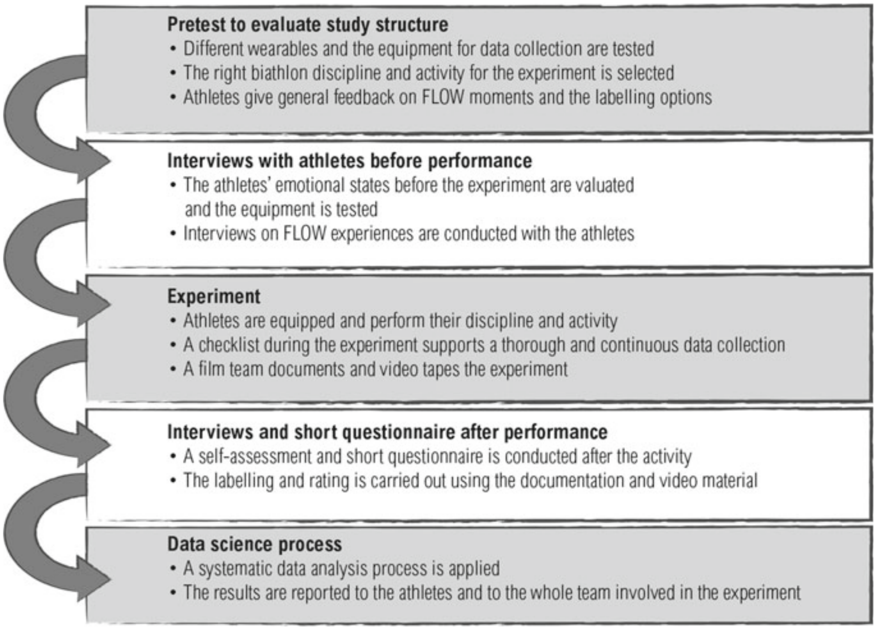

Fig. 2 Study design

biometric data was synchronized with the video data. At the beginning, in the main break, and at the end of each training session, the athletes filled out a short questionnaire on their perceived valence, arousal, flow experience, and general state of fitness. To measure flow, the flow short scale with 13 items was applied (Rheinberg et al. 2003) and used to set data labels for the data analysis. Furthermore, interviews were conducted on the emotional and mental challenges experienced in a normal training session, individual procedures for optimal preparation at the shooting range, and strategies to minimize errors. Figure 3 shows the predictive physiological pattern as a result of the data science process.

The light-colored bars show the hits. The darker bars show the misses. Where the light bar exceeds the dark bar there are more hits than misses and vice versa. The black line displays the hit rate (right y-axis) in the corresponding characteristic of the physiological pattern. The x-axis shows the value of the physiological pattern, which is used to predict the probability of hits and misses. Several combinations of physiological signals measured with the Empatica E4 device have been examined. In this study, a physiological pattern consisting of 95% HR and 5% EDA has been identified to be the best predictor for the hit probability. It roughly translates to the mental and physical load the athlete experiences in a certain moment. The pattern's values are relative and range from 0.0 (the minimum value of the HR and EDA pattern the athlete showed during the competition) and 1.0 (the

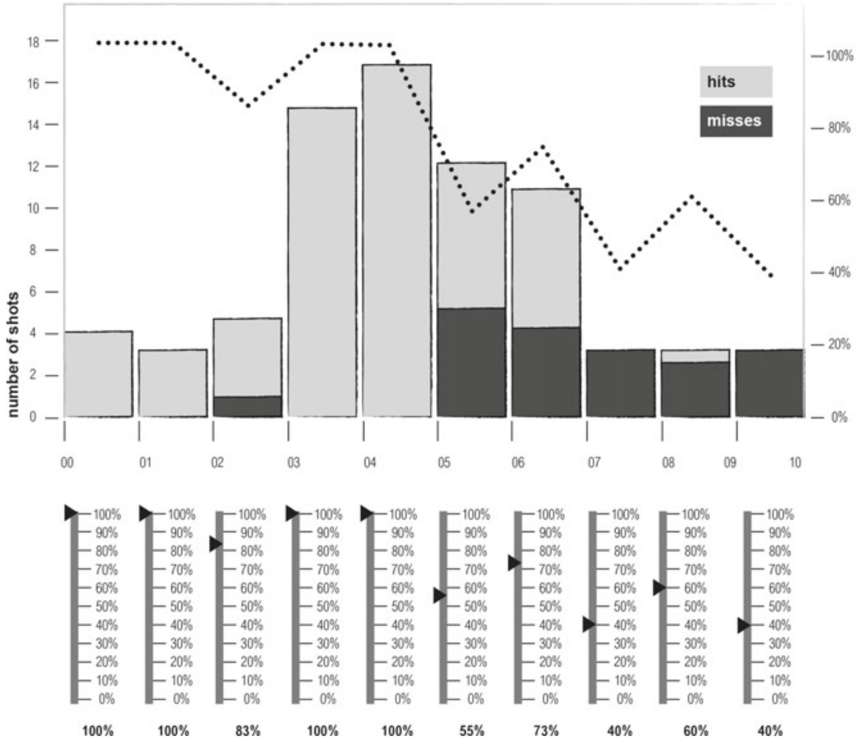

Fig. 3 Physiological pattern and hit probability

maximum value the athlete showed during the competition, i.e., high heart rate and EDA). At the bottom of the figure, corresponding hit probabilities are displayed.

Based on 100 shots in competition mode, an average hit rate of 77% and overall flow experience of 83% was achieved. There is a non-linear relation between the physiological pattern and the hit probability. The most notable result of the analysis is that there seems to be a threshold above which the hit probability drops severely. When arriving at the firing range, athletes typically show a high value of the physiological pattern. By relaxing and focusing, they can lower the value and increase their hit probability. At half of their individual maximum value of the physiological pattern they reach a hit probability of nearly 100%. Consequently, athletes might be able to improve their shooting performance if they learn to sense if they have already reached the optimal "flow level."

The results were integrated as meta information in a training video illustrated in Fig. 4.

As a limitation of the study, it has to be stated that the applied dataset was small and therefore unlikely to represent all possible states and events during a competition. A larger dataset would allow for a more fine-grained estimation of an

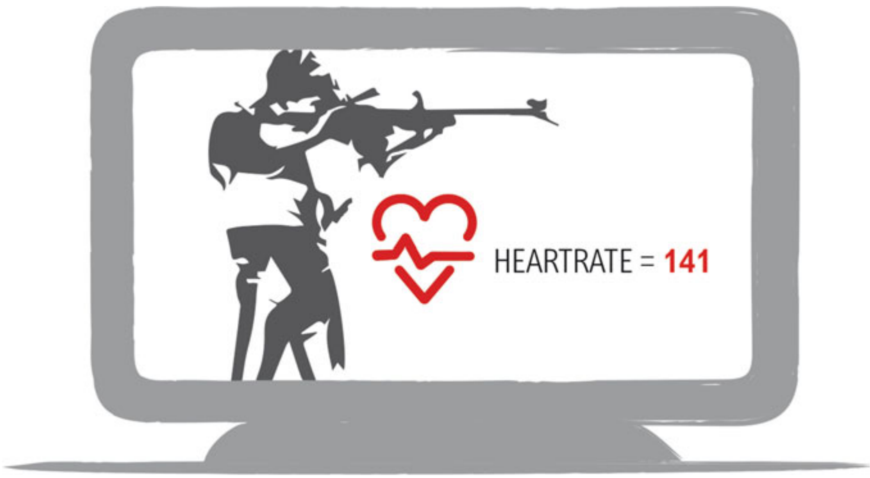

Fig. 4 Metadata in video (*source* https://youtu.be/tiQwXrbwOQc)

individual athlete's optimal state and highest hit probability. Additionally, more advanced machine learning procedures for the data analysis and classification could be applied to a larger dataset.

5 The Future of Emotion AI Technologies in Sports

Sport offers plentiful opportunities to experience flow. Whatever words are used by athletes to describe flow experiences, flow is always associated with the most precious moments of physical performance, mental productivity, and emotional balance. Yet the flow state seems mysterious to athletes and coaches alike and very hard to generate in a systematic way. The aforementioned studies of the TAWNY research team showed that (1) AI-based approaches have the potential to measure and quantify human flow states in the near future and (2) flow measurement can be applied in sports scenarios. These findings suggest that the systematic work on optimizing flow as an affective state is an additional dimension of preparation like training, nutrition, or psychological motivation, useful to achieve high performances.

The measurement, analysis, and interpretation of complex human states in sports contexts like flow may add value to various actors engaged in sports including athletes—pros as well as amateurs, coaches, spectators—in live or media settings, and media and broadcasting. Table 1 gives an overview of different application scenarios of Emotion AI from the perspective of different stakeholder groups in sports.

Table 1 Potential application of emotion AI

Actors in Sports	Scenarios for the application of Emotion AI
Professional and amateur athletes	• Use emotion analytics to maximize performance through self-optimization comparable to the "quantified self" phenomenon of self-tracking with help of fitness trackers and wearables • Keep long-term emotional diary to train mental fitness • Optimize contest and race preparation • Increase safety in high risk sports activities • Compare not only performance data but also emotional indicators with other athletes and sport idols • Improve training by choosing the ideal skill and challenge ratio based on flow theory
Coaches	• Valuable data to develop training plans • Prepare mentally for championships • Data helps support prevention, diagnosis, and therapy • Prevent accidents in overload phases • Compare athletes
Media consumers and spectators of live events	• Enrich media content not only with tech-metadata (e.g. speed, distance, etc.) but also with affective metadata of the athlete (e.g. overload, flow level, etc.) • Generate an immersive experience by providing access to the athlete's emotions during the race • Generate crowd emotions and real time interaction with the audience during live events • Optimize event programs
Media production and sport broadcasting	• Generate on-screen meta data and additional statistical data • Create second screen services • Ongoing consumer research

In the professional context, Emotional AI analyses may be used to enhance athlete's performance, to better understand why certain states occur, and what impact they have. They may further allow calculation of how much stress is positive, when it turns negative, and even when it shows long-term effects on athletes' health.

For amateurs, Emotion AI may allow athletes to better adjust their training to their mental conditions and serve as additional stimuli—helping them to stay enthusiastic and train diligently. Athletes' different mental and emotional states in moments before the start of a 100-meter run, for example, may serve as additional dimension for comparison.

With Emotion AI, coaches do not have to solely rely on empathy or their psychological knowledge to create their training plans and individual exercises. Instead, they can use real-time insights regarding psycho-psychological conditions of athletes to make exercises and routines even more effective and even less stressful.

Sport fans and spectators at live events or in front of the TV could have access to additional information about what it is going on in an athlete's mind and body with Emotion AI. What is the level of concentration, nervousness, flow, fear of failing, excitement, confidence of a favorite tennis player during match ball, or a soccer hero during a penalty shootout? This would be a totally new information layer in fan conversations as well as in live event experiences.

Sports broadcasting, to a great extent, benefits from the analyses provided by the commentators and experts—often former professional athletes or coaches. They rely on all kind of statistics, video recordings, simulations, comparison, and provided data. Often it is not the hard facts and technical aspects that make sports events such as world championships or Olympic games so unique and fascinating for the audience, but rather the human emotions, successes, tragedies, and the atmosphere. Thus, providing additional statistics and analytics based on Emotion AI as metadata may help to raise media experiences to the next level.

There is still much to explore in order to fully understand what is going on in sports scenarios. Additional Emotion AI-based methods may help researchers and practitioners to gain insights and accelerate the decoding of unknown questions and secrets. We are aware that some of the presented ideas and scenarios will take time to evolve, however, we are quite sure that others will come true in the very near future. Driven by technological advances and coupled with enormous business opportunities, Emotion AI has the potential to radically change the way we participate in and consume sports.

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Human Interaction Technologies

Strategies to Reimagine the Stadium Experience

Ben Shields and Irving Rein

Abstract

Despite the challenges presented by seemingly limitless sports and entertainment options, increasing ticket cost, and transportation issues, Shields and Rein argue that the in-stadium sports experience is important and worth fighting for. To persuade fans to spend their time and money attending sporting events, they contend that sports organizations will need to rethink their core proposition. They offer four strategies to solve the problem of fan attendance in the future: First, introducing scarcity. Second, eventizing the sports calendar. The third and fourth strategies, making the stadium experience frictionless and utilizing satellite stadiums, respectively, will require leveraging new technology including augmented reality and virtual reality. Embracing these strategies may not be easy, but they will be essential to preserving and reinvigorating stadium attendance going forward.

1 Attracting Fans to Stadiums in the Future

In the ever-changing era of sports technology, it is difficult to discern what fans want. How will their interests change over time? What will it cost to adapt to these changes, and who will pay for it? For sports organizations, there's never been a

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more challenging time to both attract attention and develop meaningful long-term fan relationships.

Nowhere are these challenges more acute than at the sports stadium. Persuading fans to leave their homes, buy a ticket, and spend the time attending a sporting event will be a tougher sell in the future—and this was a challenge even before the pandemic of 2020 that upended completely the sports world. There are a number of reasons why attracting fans to venues will be more difficult:

– *Better media experience*: The mediated viewing experience is becoming increasingly fast, cheap, easy, and high quality. Advances in wireless networks and higher picture resolutions will only enhance the viewing experience, not to mention continuous improvements in virtual reality (VR) and augmented reality (AR). The on-demand economy means that fans can also get anything delivered to their home with the touch of a button.
– *Infrastructure constraints*: Although teams can help facilitate traffic to the games, make parking available, and promote more efficient transportation options, cities are only getting denser and more populated. In many markets around the world, it will take major infrastructure spending to make it easier for fans to get in and out of the stadium. It is hard to believe there is enough funding to facilitate this in the next 25–30 years.
– *Increased competition*: People have more compelling options than ever before when it comes to how to spend their time and money. Video games, concerts, films, television, social media, malls, and tourism all compete against attending sporting events. In some cultures, stadiums are also competing for time with all-encompassing corporate campuses such as the Googleplex, a venue that blends work with leisure, enabling employees to work in an environment with a level of accommodation on par with theme parks, sports arenas, and playgrounds.
– *Climate change*: With the clear science of climate change as a backdrop, sporting events in the future will likely encounter unforeseen weather and other environmental barriers to attendance. The rising temperatures at sporting events like the Australian Open have caused tournament organizers to think differently about the experiences of both the players and the fans, and the lack of snow in winter sports presents an equally challenging situation for organizers of these events. Climate-related factors will further complicate the attendance challenge in the future.

Why is focusing on preserving and invigorating the stadium experience so important? While media will inevitably remain the most important revenue stream for sports well into the future, stadium revenues are not insignificant and remain an important cornerstone for the balance sheet of any sports league or team. Moreover, fans at the stadium are not merely a studio audience. Going to the stadium to experience sports firsthand is a proven tactic to connect with new fans and increase the avidity of current fans. It delivers a shared experience and sense of community that is difficult to replicate elsewhere. Alternatively, if fans stay home to watch the game because it is more convenient, fan bases will erode, and eventually there will be no game to watch. Games become less authentic and attractive if filling a stadium means paying people to go to games. Perhaps the next logical step will be creating computer-generated fans as realistic as the animals in the *Lion King* to create the illusion of a crowded stadium. This works well for a Disney film, but it does not seem credible for sports teams.

In short, attracting fans to stadiums is something teams and leagues must continue to invest in and get right. How can teams/organizations solve this problem? We anticipate four strategies will be essential to attracting fans to stadiums: scarcity, eventizing, frictionless experiences, and satellite stadiums. If sports teams and leagues implement these strategies, we believe, first and foremost, they will attract more fans to games. In turn, this will have a halo effect on the other products/services in their portfolio (e.g., media consumption, merchandise, sponsorship, gaming). This will not be easy—and in our view, it will require a fundamental transformation in how sports leagues and teams do business.

2 Scarcity

Traditional sports are in danger of overexposure. In economics terms, the market is becoming oversupplied with the product relative to the demand. For example, Major League Baseball has 162 regular season games per year. With only the most avid fans paying attention throughout the entirety of the regular season, it is not surprising that MLB's attendance numbers have continued to slip (Associated Press 2019).

By contrast, the National Football League (NFL) has emerged as the most successful sport in North America based on revenues (Soshnick and Novy-Williams 2019). Currently, teams play only 16 games in a season, the majority of which are on a Sunday. The strategy creates anticipation for the next week's game. In 2019, all but three stadiums were at or above 90% capacity (http://www.espn.com/nfl/attendance/_/sort/homePct). The Indian Premier League, the popular cricket tournament, occurs once a year and lasts for less than three months. The FIFA World Cup, one of the industry's marquee events, is played every four years for a month.

What's operating here? All of these sports offerings benefit from scarcity: The social psychological phenomena that people want more of what they can't have. Robert Cialdini identified scarcity as one of the six key influence tactics based on robust research into what persuades people (Cialdini 2004). It runs counter to the always-on, at-your-fingertips popular culture in which we now live. If something is always available, it becomes less valuable.

To avoid overexposure, sports organizations need to actively manage the scarcity of their product. They should take two specific measures to protect their most valuable assets: reduce the number of games and embrace shorter formats.

2.1 Fewer Games

Many sports leagues need to reduce the number of games in their regular seasons. The traditional and prevailing school of thought is that more games increase revenue and keep fans engaged (and away from other competitive leagues/teams/entertainments). But in reality, filling a stadium consistently over a long season is becoming a difficult challenge for many established sports.

There would be a number of benefits to shorter seasons. The first is greater fan interest. By decreasing the supply of games, it would increase the demand. This move is largely without precedent in the industry, as more games have always been better. But we believe for leagues bold enough to embrace scarcity, they will see stadiums filled to capacity (often with higher ticket prices) as a result. Second, it would create opportunities during the year for other events outside the regular season. With the success of the offseason, the industry is now learning that there are plenty of ways to captivate the fan without staging a game. Leagues can have shorter seasons, but also maintain, even enhance fan engagement. Finally, it could reduce wear and tear on players. Injuries are a pressing issue for all sports leagues as expectations for physical excellence and endurance escalate. Kevin Durant and Klay Thompson getting seriously injured in the final game of the 2019 NBA Finals are examples of the danger of pushing athletes to their limits.

As a league with a reputation for future-oriented thinking, the NBA is seriously considering reducing the number of games from its current 82 game season (Arnovitz 2019). Commissioner Adam Silver said, “I’m a traditionalist on one hand, but on the other hand [the 82-game schedule is] 50 years old or so, presenting an 82-game season, and there’s nothing magical about it” (Helin 2019). If (or more likely when) the league moves in this direction, all stakeholders—teams, fans, media, sponsors—will benefit from a scarcer product, and it will inspire other leagues to do the same.

The most obvious counterargument is that the fewer number of games would reduce revenue, which no one in sports wants. Shorter seasons should yield higher quality games and create opportunities for new revenue-producing events and offerings that can help offset any loss in revenue. Critically, sports leagues can no longer view themselves as volume businesses: They must consider their brand, competition, and athletes’ health to sustain over the long-term.

2.2 Shorter Formats

The rule of scarcity also applies to the format of the game. Sports organizations will need to consider alternative formats to create shorter offerings and leave fans wanting more. Fan attention spans are shortening, work is creeping into personal life, and other competition for time and attention is at fans’ fingertips. Sports leagues/teams must be sensitive to this new marketplace dynamic and experiment with different, often shorter formats. This is especially important for stadium attendance, as the time commitment required to travel to and from a game can be an obstacle.

Traditional formats run the risk of deterring the newest generation of fans from attending sporting events. For perspective, the average Major League Baseball game lasts more than three hours. Meanwhile, the average Fortnite battle royale game can last 15 min, not a lot of time for a professional player to win three million USD (Perez 2019). As Millennials and Generation Z become the largest and most powerful fan groups in the sports industry, it is not safe to assume this generation will watch games like their parents' generation. The highlights and social media experience are increasingly so compelling that it might not be worth the time to invest in going to a game.

Sports organizations in the future must consider new formats that are tailored to this emerging fan culture. The England and Wales Cricket Board is heading in the right direction with its Hundred cricket tournament. Following the successes of the Indian Premier League's Twenty20 format, they are making cricket shorter and simpler (Ahmed 2019). Naturally, cricket traditionalists have decried this version of the sport. The Hundred is not replacing five-day matches but creating another product in the portfolio of cricket offerings. Doing something new while still appeasing the core audience is always a difficult balance to strike but doing nothing is no longer an option. It is too early to tell how the Hundred experiment will turn out, but we believe it represents a harbinger of the types of format changes sports will need to embrace.

The Olympics in particular has shown a willingness to adapt to changes in fan tastes and preferences. The summer games are now home to three-on-three basketball. Each game is a ten-minute period. For example, if a team scores 21 points before the ten minutes is complete, they win. If not, the team with the most points at the end of ten minutes wins. There's also a 12-second shot clock, compared to the 24-second shot clock in the NBA game (https://www.usab.com/3x3/3x3-rules-of-the-game.aspx). The game is fast moving and easily digestible.

These shorter formats are not only good for creating scarcity and attracting attendance, but they can also help drive participation. Golf, for instance, is facing participation challenges necessitating format innovation (Ginella 2019). TopGolf, an experiential driving range that includes hi-tech golf simulators in addition to restaurants, bars, and party suites, is thriving in part because of its differentiated format. We are not suggesting the PGA Tour offer TopGolf tournaments, but embrace similar alternative thinking with regard to its format to secure the survival of the sport in the future.

The changeover to adopt scarcity will not be easy. Team owners will likely reject any possible hits to revenue, even if a short-term loss will result in a greater gain in the long-term. Making it even more difficult to embrace scarcity—and the various tactics we've discussed here—is the rising cost of franchises, players, and the shifting financial obligations for new stadiums and sports facilities from the cities to the owners. Owning a team has long been a vanity exercise for wealthy owners, heavily endowed universities, and cities desperately in need of an image boost. That practice will not end but be muted by competition and new technologies. And it will require owners to embrace experimentation and risk-taking to stay ahead of future challenges. Scarcity is one strategy that we believe the winners will adopt and maximize to keep fans attending games.

3 Eventizing

Eventizing is the strategic transformation of a moment on the sports calendar into a must-see event. Isn't a game by its very nature an event? Not in our view. Events have a distinctive quality compared to a regular season game. They have unique storylines because of the format, location, players, and stakes. As a result, events break the rhythm of the season and give fans, media, and sponsors new reasons to pay attention and converge on the stadium.

The most obvious examples of events in sports are championships like the Super Bowl and World Series. But events are not limited to championships. The Indy 500 has special significance on the calendar for casual and hardcore fans worldwide, but the winner does not claim the Indy Car championship. It's also important to point out that events do not need to be tied to an actual athletic contest. Out-of-season events represent a compelling hook to keep fans engaged year-round while other leagues are playing. For example, drafts have emerged as jewel events on the NFL, NBA, and WNBA calendars, as they thrive on speculation and fans' hopes that their teams can improve.

Of course, creating too many events could lead to commoditization, the exact opposite of what they are intended to do. Keeping the scarcity strategy in mind when creating and managing a portfolio of events will be essential.

In the future, we expect to see sports organizations continue to innovate with the eventizing strategy to attract fans to the stadium. Specifically, the game, season, and offseason will all become eventized.

3.1 Eventizing the Game

The first and most obvious opportunity to eventize is at the game-level. Sports organizations will continue to build additional attractions and hooks to engage a wide range of fans (not just the avid ones). The idea is to offer experiences fans cannot get elsewhere, especially via media. The Texas Longhorns football team, historically a blue-chip brand in college football, reversed attendance declines through a combination of stronger play and outdoor stadium attractions that feature concerts, food, and other entertainment on gameday. These offerings often attract more fans than can fit in the stadium. Those who don't get in watch the game on big screens outside the venue, adding to the overall excitement of the event (Smith 2019).

Formula 1 has also implemented the eventizing strategy to turn each Grand Prix weekend into a spectacle-like atmosphere that culminates in the race on Sunday. This strategy has kept a sport challenged by a lack of overtaking on a steady growth path in attendance, media consumption, and other key metrics. For example, the Abu Dhabi Grand Prix is known not only for being the final race of the season but also for the big-name music acts that perform on the nights leading up to the races. Liberty Media, which owns Formula 1, has often described each of its races as a Super Bowl. And with a season consisting of more than 20 races, they have a Super Bowl in a different country every time. The game (or race in the Formula 1 case) serves as the platform around which to build a broader entertainment offering that is different from watching the race at home.

Should every Philadelphia Flyer game be produced like the Stanley Cup Finals? From a pragmatic standpoint, the answer is no. Most teams will not have the budget to accommodate full-scale eventizing for every regular season game. But there are small wins that could contribute to meaningful differentiation in the market. For example, naming the event can help a rivalry standout in a media-cluttered environment. When Texas and Oklahoma play in the Red River Showdown, or Alabama and Auburn meet in the Iron Bowl, the naming serves as a shorthand for the match-up itself. It elevates the contest in a way that lifts it out of the cluttered football schedule in the Fall.

Another option is to play the game in a distinct location. Shared spaces—also known as convertible stadiums—can be a particularly cost-effective option. One encouraging move toward convertible stadiums is The NHL Winter Classic, a hockey game played outside in an unconventional setting such as a football or baseball stadiums. Other examples are the Yankees and Red Sox have played in London Stadium, the site of the 2012 Olympics opening and closing ceremonies as well as track and field events, or The Fortnite World Cup being held in the Arthur Ashe Stadium, home to the U.S. Open tennis tournament. These events have a dual advantage: The venue already exists (no need to create a new one), while also attracting attention through perspective by incongruity: putting two relatively dissimilar things together for the purpose of creating a new experience.

3.2 Eventizing the Season

In the future, sports organizations will need to reexamine what a season means. A season is the way a league defines/sets its schedule. Games are played in a structured fashion with particular time periods, which historically follow the calendar. In the United States, fall is football, winter is basketball, spring and summer are baseball. Today's sports leagues are already ignoring the calendar seasons, as many seek to become year-round entertainment. We are proposing a redefinition of the concept of a season, moving towards a more tournament or championship-based strategy.

Long regular seasons can become background noise for everyone but the most avid fans. If reducing games are a financial challenge in the short-term, creating mini seasons within the season with special events along the way will incite fan interest and generate revenue. For example, to address the problem of 162 games in an MLB season, we could imagine MLB changing its schedule to two half seasons. Instead of playing the traditional All-Star game, the MLB would host the first half playoff with the winning team earning a spot in the World Series. Then play the second half season and stage another playoff. The two halves would meet at the World Series, perhaps adding teams from Seoul, Mexico City, Tokyo, and other hotbeds of baseball. The NBA is also considering similar ideas that include the possibility of a series of tournaments throughout the season (Helin 2019). These tournaments could mean a higher price for the tickets for each event and a different way of selling the season.

3.3 Eventizing the Offseason

Traditionally, when a sport is not in season, leagues and teams may lose the battle of attention to other competitors. To fill this void, the sports experience of the future will continue to create and promote non-game events. Possibilities include drafts, free agency periods, trade deadlines, practice seasons, sponsor activations and experiences, and training camps. These and other strategies to engage the fan when there isn't a game also represent opportunities to sell tickets to stadiums via watch parties.

Innovative sports leagues look at their sports as 365-day-year offerings that go beyond what happens on gameday. The NFL Draft started in a hotel conference room where teams would select young promising college players for their roster. The impact of each of the selections usually would not be known for months, if not years in the future. ESPN and the NFL transformed the NFL Draft into a spectacle, which culminates in a weekend-long event that attracts more television viewers than any other real game being played at the same time. The league has recently turned it into a traveling event where a different city each year hosts the calling of player names outdoors for thousands of fans to join. The Draft is an important example of the potential of non-game events. The NBA has seen similar success with their free agency period. NBA free agency is now more talked about on Twitter than regular season games (Harding 2019).

When eventizing the offseason, the role of the athlete becomes particularly important. The player has replaced the movie star as an authentic and engaging public figure. Being a professional athlete becomes the platform for building a star as sports engagement moves from team-culture toward star-culture. The need for personal attachment has always been there, as the player is engaging to fans in a way that the team or venue is not, but social media have provided fans with more content and access to these athletes on a year-round basis. The successful star not only represents a number of identifiable or aspirational characteristics, but also has the media savvy to showcase those characteristics across multiple channels. It is an extension of what can be referred to as the "Kardashian Effect," the multifaceted personality of a player becomes more and more important to generations that have grown up with the expectation to interact with stars. Athlete narratives are therefore essential to successful eventizing of the offseason. They keep storylines going and create anticipation for the season to begin anew, which only helps drive ticket sales to the venue.

The days of fans spending significant time and money to attend a game that they can watch easily, cheaply, and with better quality via media will be numbered in the future. To counteract this trend, sports organizations will need to create and sustain more events—providing experiences that fans cannot get elsewhere. And they will need to look to eventizing the game, the season, and offseason to create a compelling portfolio of sports holidays throughout the year.

4 Frictionless Experiences

The most influential disruptor companies like AirBnB and Uber have taken the friction out of the customer experience. Friction refers to all the "pain points" a customer might have during the experience. For example, AirBnB makes it easy and safe to rent your home out to strangers or to rent a room in someone else's home.

In the sports world, there are many points of friction that make going to a sporting event more of a hassle than it might be worth. These include fighting traffic to get to the stadium, parking, standing in lines for food and drink, finding your seat, getting out of the stadium, and making it home relatively stress free. It is no coincidence that the Fast Pass has been so successful for theme parks like Disney World and Universal Studios. People don't want to have to wait and be inconvenienced. Naturally, the same is true when it comes to the sports experience.

The successful sports stadiums in the future will dramatically eliminate the friction involved in attending a sporting event. This will combine both human interaction and technological assistance. Fans will want the touch of the personal and the convenience of technology. Importantly, technology of the future will not be obvious to the user, but rather integrated into the sports stadium experience. Stadiums will reduce friction in three key phases of the gameday: pre-game, in-game, and post-game.

4.1 Pre-game

Technology has the potential to implement viable solutions for the starting point of the fan experience: Getting to the stadium. As traffic in cities continues to worsen, transportation will become an even greater impediment to attendance, making it a more pressing problem to solve. Ultimately, getting to the sporting event needs to be frictionless. Just like ordering dinner from Postmates.

Some of the solutions will require partnerships between the cities and the teams. For example, in Los Angeles, a market notorious for its traffic problems, the Los

Angeles Dodgers, and Anaheim Angels use an old-fashioned transportation system—buses—to get people to their respective stadiums quickly. The cities have created dedicated bus lanes to help make the trip as easy as possible. Of course, fans have to first drive to the various pickup points and then drive home, but it is a step in the right direction.

Over the long-term sports organizations will need to explore different, more innovative forms of transportation to get fans to the stadium. One option that must be considered is flying cars. The pipe dream of Jetson's fans is becoming more realistic than ever before. Companies like Boeing and Porsche are developing this technology and predictions are that by the mid-2020s passenger drones will be available to consumers to purchase (Brown 2019). Of course, technical feasibility is only one part of the equation; regulation will need to be developed to enable widespread use of the technology. But the question of flying cars is no longer one of fantasy. And to deal with the ongoing transportation problems to and from stadiums on congested roadways, forward-looking teams will seek new arrangements with local cities to open up the airpaths to drive attendance.

If infrastructure issues of grounded and/or flying cars are too much to overcome, then sports organizations will have to create other experiences to compensate for traffic. For example, MLS teams like the Portland Timbers and Seattle Sounders benefit from fan-led marches to the match, events that not only encourage people to walk to the stadium but also create a community feel around the game.

Once fans arrive at the stadium, the check-in experience also needs to be frictionless. The startup Clear is a good indication of where the industry is headed. Clear uses biometrics to do a quick security scan of the fan, ensuring that the lines to get into the stadium move quickly and efficiently. Eventually, all tickets to sporting events will be mobile (or paperless), which will make the "ticket-taking" process simple and easy. From there, fans will need a Waze-like navigation experience to find their seats with the most efficient route possible, accounting for real-time information about the crowdedness of the concourses and the length of concession lines. Along the way, having stadium representatives welcome fans by name and assist them based on their preferences will be essential to adding the human touch and making fans feel like they are at their home away from home.

4.2 In-Game

Being at the game also needs to be as easy as using an Amazon Echo. After all, when watching a game at home, stats about the game can be called up on your phone in an instant, food can be ordered with the touch of a button, and you can control the environment (light, sound temperature) to your liking. The stadium experience must provide something so compelling that fans would give up the conveniences of home to watch from the stands.

From a technology standpoint, enhanced Wi-Fi connectivity is putting stadiums in position to deliver better experiences. This will only get better in the future with the advent of 5G, which will open up a host of innovative fan experiences.

These include the use of AR (either through phones or glasses) to superimpose stats on the field in real-time. Highlights and behind-the-scenes access will also be more easily accessible via mobile phones during games. It is likely that in-game betting will also be a central feature of the stadium experience, much like fans historically wagered on horseraces. And it will all be personalized based on your preferences, not unlike a Netflix recommendation engine.

But technology will not be the only way to reduce friction in-game. Stadiums will also find ways to reduce fan pain points and entice fans to keep coming back. Mercedes-Benz Stadium in Atlanta, Georgia is an avatar for a frictionless in-stadium experience. To be sure, they have state-of-the-art technology, as they have moved to a mobile-first cashless system, which is reducing the wait time in lines. Yet there is also a human element to the stadium. Most notably, they have disrupted the concessions business. In an industry where $8 hot dogs and $13 beers are the norm, they have slashed prices to just $1.50 for a hot dog and $5 for a 12 oz. beer. This is unexpected and an interesting juxtaposition in the context of a technologically advanced arena. The concessions are so cheap and of comparatively high quality that fans are even showing up early before games to spend money. It may come as no surprise that the concession revenues are growing and outpacing projections (Bogage 2019). Low pricing for concessions is not technologically advanced, but it is a critical element of the fan experience that Mercedes-Benz Stadium is creating.

The ultimate in frictionless experiences is the introduction of the tiny house at the BMW Open at the Medinah golf course outside of Chicago. The tiny house is strategically placed on the course by the 14th tee. Each 350 square foot unit includes two queen sized beds, a fully stocked kitchen and bar, a bathroom, and a veranda which allows the renter to become part of the golf tournament. The renters are close to the action, able to talk to golfers, and even offer them a beer (or, in case of emergencies, use the bathroom). Tiny houses can be expanded to other golf tournaments, cross country skiing, or bicycle races (Greenstein 2019). This is yet another innovative concept that enables the fan to get closer to the sport in ways that no one ever imagined.

4.3 Post-game

Successful stadiums in the future will employ similar strategies as the pre-game to get fans out of the stadium and home quickly and safely. The Miami Dolphins are installing pedestrian tunnels to keep fans out of the way of cars and increase the flow of traffic out of the stadium. The New England Patriots are giving free parking to fans who leave at least 75 minutes after the game ends (Fischer 2019). We will see more innovations in post-game departures going forward.

The post-game experience will also be more systematically focused on fan retention. The best organizations will encourage people to follow up on the experience, tell their friends about it, and make plans to come back to the venue. A number of teams are offering their fans in-game experiences that culminate in events after the game itself. University of Alabama, for example, holds an auction for an all-day fan experience that ends with the opportunity to attend a post-game media conference with Nick Saban. Other college football teams, such as Northwestern University, hold raffles or auctions to win a trip with the team to an away game. Teams, like restaurants and other businesses, offer discounts on future games, memorabilia, and food concessions to incentivize return trips. These are important efforts to follow up on the fan experience and try to deepen their engagement going forward.

The stadium app will be a critical vehicle for the post-game experience. For example, the Tottenham Hotspurs stadium app is designed to help fans make a day of their visit. Using features like an interactive stadium map and selfie wall (Symcox 2019), the app encourages fans to stay on the grounds for as long as possible. The stadium was built from the ground up with the app in mind, integrating the frictionless technology into all aspects of the venue. Not only does the app increase revenue, but it also mitigates travel time for the fans, making their visit to the stadium worthwhile (McCaskill 2019). In the future, the app might be able to summon your flying car from the parking cloud.

For much of sports history, the in-game experience has been the primary focus of sports organizations. With more pressure to fill venues, organizations of the future will not only need to enhance the in-game experience, but also ensure the pre-game and post-game is thoughtfully considered as part of the fan engagement strategy. This fan-centric approach will separate the stadiums that are sold out from those that struggle to fill the lower bowl.

5 Satellite Stadiums

Up until this point, we have been discussing strategies that we believe will be effective in attracting stadium attendance in the future. The last strategy approaches the problem from a different perspective. We believe sports organizations should consider ways to bring the stadium—or the team—to their fan bases. This is where the concept of satellite stadiums could be particularly helpful. To be clear, satellite stadiums will only succeed if the core experience at the stadium is healthy.

There has been much written about the “Third Place,” a social setting separate from the two usual social environments, home and work, with Starbucks being the quintessential example. The concept of the Third Place can be applied to sports, serving as a social setting separate from home and stadium. This satellite stadium environment would offer fans advantages of the in-stadium experience, such as community and team affiliation, without having to travel far from home. This is not simply a sports bar, but rather a digitally driven satellite location that emulates key aspects of the sporting experience while offering new and exclusive ways to engage with a team. An early example of such a space is the Sportsbook: A luxury space where people can come together to bet on and watch any sport in the world on large interactive screens. Examples of modern Sportsbooks can be found in Las Vegas’

Caesars Palace, The Westgate, and the Venetian. Other existing models of satellite stadiums include Manchester United's experience centers (Reed 2020). These physical and digital spaces allow fans across the globe to meaningfully engage with a team without even going to the game. Liverpool FC is another model with over 280 supporters clubs across 90 countries (https://www.liverpoolfc.com/fans/official-lfc-supporters-clubs). The soccer teams will occasionally show up in these countries for one game to continue to stoke-up interest.

Satellite stadium environments could be configured in a number of ways: a space could represent one club, be limited to league teams, or it could be a seven-day all-year experience with a multitude of sports input (NBA on Wednesday nights, WWE on Fridays). It would not replace going to the park or the stadium, but rather encourage followers to build a community around a team or even organize to go to the game. The satellite stadium patron would be constantly reminded through raffles, bussing opportunities, visits by team personnel, and other inducements to go to the game in-person.

There are existing permutations of this concept in the museum realm: multi-room, experience-based, interactive, and immersive "cultural playgrounds" that encourage participation (Johnson 2018). A sports version might look like an expansion of TopGolf with multi-room sporting experiences. The advent of technology and advanced simulations offer the fan the opportunity to defend against Lionel Messi, return a serve from Serena Williams, or swing at Justin Verlander's slider in real-time. Other ideas of what such a space might look like in the future could include hologram projections of games allowing fans to watch from all angles or VR headsets that teleport fans inside the bullpen or on center ice while the game is in action.

A good example of a satellite stadium is Disney's NBA Experience at Walt Disney World's Disney Springs. Disney visitors are asked to pick their favorite team and a personalized nickname. Customers can compare themselves against their chosen professional basketball players in events such as shooting and dunking. There are stations in which they can learn the histories of teams, further ingraining visitors in the cultures of said teams. The combination of Disney's technology and the NBA is a format which is easily digestible and further deepens the relationship between the visitor with the NBA and Disney (McLellan 2019).

The satellite stadium experience is not designed to replace the actual in-stadium experience. The University of Michigan Big House will remain the Vatican of Big Ten football; those institutional sports markers are not going to disappear. Rather, the satellite stadium recognizes the technological advantages of an intermediate yet immersive experience while still encouraging fans to deepen their commitment to the team. Additionally, these satellite stadiums would allow leagues to test out new technologies on a smaller scale before launching them in full stadiums. And, perhaps most importantly, satellite stadiums can help create demand for fans to visit and buy tickets for the real thing.

Another variation of the satellite stadium can use VR to simulate the experience of being at the "real" game. It is important for these virtual simulations to recreate —or better yet, redefine—the sensory experience of attending the game. Today, VR is largely a visual and audio experience. In the future, it will also need to activate other senses like smell (replicating the aroma of the grass field), touch (catching a foul ball in VR), and taste (enjoying a beer from the virtual beer guy). In addition, the virtual experience will also be more social than it is today. A fan could watch a game with her friend in a virtual stadium while they are in different locations. These virtual experiences could become so convenient and immersive that fans will pay for them.

Satellite stadiums will be an important innovation opportunity for sports organizations in the future. Key trends including increases in urban population, climate change, and vast improvements in VR and AR will lead to sports organizations exploring this concept with rigor. The downside is fans become so enamored of the satellite stadium experience that buying a ticket and attending a game at the "real" venue becomes less attractive. The other strategies discussed in this chapter can help mitigate this potential downside.

6 What Does the Future Hold for Sports Stadiums?

The challenge of persuading people to leave their homes and spend time and money in a brick-and-mortar location is not unique to sports. Shopping malls and movie theaters find themselves in a similar situation, and their responses on the whole have been mixed. Sports has something they do not—a live experience with an uncertain outcome. This is a significant advantage and because of it, the industry should have confidence that the current stadium experience will not disappear.

At the same time, sports organizations should look to the vacant malls and movie theaters as cautionary tales of what can happen without getting out in front of cultural and technological changes. The strategies discussed in this chapter—scarcity, eventizing, frictionless experiences, and satellite stadiums—are promising solutions to revitalizing stadium attendance in the future.

One final consideration for the future of sports stadiums: It is not every day that a sports organization has the budget and public support to build a new stadium. But when it does, we see two models rising above the rest. The first is the mega-complex: A destination center with attractions that not only include the sports stadium, but also retail stores, offices, residences, and hotels, making it an attractive venue year-round. Events function as the anchor for these mega-complexes. For example, the LA Stadium and Entertainment District (LASED) at Hollywood Park is set to host the 2022 Super Bowl in addition to the opening and closing ceremonies of the 2028 Olympics. LASED is designed to create an epi-center experience to get customers out of their homes. The project was summed up by Rams' COO Kevin Demoff: "How do we do something that is completely unique within Southern California, that would change people's view of sports and entertainment districts?" (Clarke 2019).

The second configuration is a series of stadiums or arenas that will become deeply integrated into the existing center-city ecosystem. This would typically be a downtown integrated sports complex. Promising examples of cities with multiple downtown stadium complexes are Houston, Indianapolis, and Minneapolis. This downtown integration enables the existing hotels, restaurants, and stores to build off the business of attracting and sponsoring sports franchises. A problem with this strategy has been that these sports complexes often are not planned but are rather haphazardly applied to the downtown core.

Whether enhancing an existing venue or building a new one, all sports organizations and teams will be forced to reconceptualize their product and fan experience and take risks. In the long run, this will be good for sports, but there might be some adjustments and pain along the way.

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Virtual Reality and Sports: The Rise of Mixed, Augmented, Immersive, and Esports Experiences

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Abstract

In this chapter, Miah, Fenton, and Chadwick examine how sports have become increasingly intertwined with the trajectory of the media innovation industries and how this extends particularly to the realm of computer-generated imagery and game playing. They consider how virtual reality, augmented reality, mixed reality, and extended reality are being integrated into the sports industries and discuss the innovation culture that operates around these experiences. They focus on how new, digitally immersive sports experiences transform the athletic experience for participants and audiences and create new kinds of experience that, in turn, transform the sporting world. Further, they analyze what this means for the long-term future of sports.

1 Introduction

Historically, sports have always been spaces of alternate realities, free from many of the constraints of everyday life. Rules that apply to the social world often do not apply to sports and, in many respects, this is what makes them uniquely exciting and interesting. For example, in contact sports such as boxing or rugby—physically

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assaulting another person is part of what the game requires of the athletes, whereas the same actions outside of that protected world would be deemed deviant behavior or even illegal. As such, sports allow their participants to explore new kinds of social interaction, in a relatively safe space, through their creation of rules and the establishment of norms that may be described as "half real" (Juul 2005). In this sense, sports have always been spaces of unreality; they are theatrical environments in which stories unravel through the struggles of competing in their pursuit of excellence and victory over one another. Yet, new technology is transforming these practices even further, creating new layers of unreality to the sporting endeavor, further relocating them into the realm of fantasy play.

By developing new forms of digital innovation that disrupt the distinction between physical and digital space, new immersive realities are being established, creating new forms of activities that resemble sports. These experiences are designed to fool us into believing that we—as participants or spectators—are inhabiting new, physical spaces, even though they are composed of film or computer-generated images, designed purposefully to trick our senses through disorientation and relocation. The inclusion of the competitive nature of games as part of the experience architecture adds to their persuasive armory, compelling us towards feeling part of the space, and tricking our senses into believing that it has physical properties. Moreover, the generation of such experiences is rapidly becoming a new form of economic currency within traditional sports, increasingly professionalized and widespread as cultural practice, as is attested by the rise of esports.

In this context, the present chapter focuses on how new, digitally immersive sports experiences transform the athletic experience for participants and audiences and how they are creating new kinds of experience, which are transforming the sporting world. Such virtual sports are especially interesting examples to analyze because they highlight the growing importance of integrating physicality into digital encounters, as a means of making them even more realistic. A good virtual sports application is described by the enjoyment of an uninhibited, fully embodied experience that permits the full range of sensorial expressions, particularly freedom of movement.

We begin by outlining different forms of new virtual realities in sport, considering how virtual, augmented, mixed, and extended realities are being designed into the sports industries in different ways. We then also consider how these may be broken down across different actors within the sporting ecosystem, from players and officials to fans and spectators. Subsequently, we discuss the innovation culture that operates around these experiences, which reveal the creative and technical impetus for their development. Furthermore, we examine how these new, virtual realities transform the sports fans and audience experiences, and discuss what this means for the long-term future of sports.

Closely related to the trends we describe is the emerging industry of esports, which is emblematic of the changes occurring around sports. Esports have shown how competitive, digital sports can be created around a range of new, immersive pursuits. This is especially interesting, given discussions about the possible creation of new Olympic disciplines that consist of virtual reality (VR) games (The Morning Show 2019). We will go on to describe how esports provides the foundation for sport's future, where this is characterized by advanced simulation technology, played out in virtual arenas. In this respect, we discuss the future of esports as being intimately connected to and reliant on the integration of VR technologies that nudge it even closer to the traditional world of sport. Tomorrow's athlete will be part human and part avatar, where presently these two components of the digital sports system are separate, united only through the legal wrangling of intellectual property rights.

In this context, we discuss the challenges faced by these dynamic industries and consider their direction of travel. We also examine what the future might hold for extended realities in sports and the implications for people living in a post-digital world. Overall, the chapter tells the story of how sports have become increasingly intertwined with the trajectory of the media innovation industries, which themselves are undergoing extensive revisioning, and how this is extending particularly into the realm of computer-generated imagery and game playing. Central to this trajectory is the proposition that sports, as forms of storytelling, tend inevitably towards such worlds where there are further possibilities to modify, monetize, and re-invent the practices of sports alongside the changing expectations of the playing public.

2 Emerging Realities

In recent years, the term virtual reality (VR) has been used to denote experiences that involve wearing a screen-based digital device on one's head to allow the sensorial experience of an imagined world. The device's on-board gyroscopes and sensors coordinate the animation of digital content so that the wearer experiences a connection between their actions and digital materials they are viewing. The consequence of these functions is the experience of a virtual world, which responds to the user's movements in the physical world, thus creating the sense that the two are intertwined and even indistinguishable. The experience creates a sense of occupying a physical space other than the one where the user is situated.

While there are now many kinds of VR platforms, these principles remain common across each of them, with new iterations achieving greater degrees of realness, either in terms of graphics or responsiveness to movements. In this context, the term *immersive* expresses a range of formats of VR, augmented reality (AR), or mixed reality (MR), where the physical reality of one's location is intertwined with the technology's digital audio, visual, and, increasingly, tactile features.

Since 2014, digital VR experiences have become commonplace, with the emergence of affordable consumer technologies, often using a smartphone as the principal computer and screen that drives the experience. For example, in 2014, Google released Cardboard, a cheap, folded piece of cardboard into which a mobile phone could be inserted, permitting the construction of a primitive VR headset.

At the time, organizations like Oculus had also developed their own VR headsets, the graphics of which were powered by personal computers. Since then, VR headsets have become common accessories and many companies, from Samsung to PlayStation, now have their own VR headsets. Moreover, the eventual acquisition of Oculus by Facebook speaks to the manner in which VR became a mainstream digital accessory, even if unit sales are still far less than mobile phones.

The development of VR has been accompanied by the rise of AR, which involves overlaying digital graphics onto the physical world using projection-based technology, thereby creating a blended interactive and augmented experience. AR is also often reliant on a mobile phone, where its camera function is employed to allow users to see digital content as if it were placed within a particular physical space. One of the most successful, early gaming applications of this kind was Pokémon Go, launched in 2016 to widespread public debate and enjoyment.

Additionally, dedicated VR headsets have pioneered these applications, notably the Microsoft HoloLens, which utilizes sensors to map out a 3D space, creating the illusion that the content is moving with the user as they walk around a physical space. Whereas Pokémon Go involved the user holding their mobile device and interacting with content using AR, the HoloLens used a headset to more fully immerse the wearer in the environment. The wearer could traverse physical space as they would normally, and the content would respond and adjust to their physical location. So, if the HoloLens appeared to create a hole in a floor, the wearer could physically walk around the hole and perceive it moving with them. This is achieved by the device's capacity to, first, scan out the physical space and then establish how it maps out the user's position within it in three dimensions.

Mixed Reality (MR) is yet another kind of extended reality that involves the merging of physical and virtual objects in real time. MR can encompass elements of both AR and VR technologies. MR was first pioneered by the US Air Force who found that human performance could be significantly improved by combining virtual objects into the real world as part of a simulation (Rosenberg 1992). The desirability of creating simulations with the goal of performance improvement, therefore, creates significant interest for sports players and teams. In most sporting realities, performance, and competitive edge is pivotal to player success and improvement. Success is often fundamental to the ongoing sustainability of the team.

Perhaps more importantly, these technologies stretch the concept of the "half real," allowing social and physical rules to be bent or broken. And there is already some cultural precedent for such pursuits, as many works of fiction engage audiences with the idea that life may be some kind of virtual space. For example, in the movie *The Matrix* (1999), Morpheus explains this idea to Neo when he is first trained in physical combat through an immersive system: "What you must learn is that these rules are no different from the rules of a computer system. Some of them can be bent, others can be broken." This opportunity, therefore, increasingly creates the kind of training and sporting scenarios that transcend what we might consider to be "real life" sports. With fragmentation and the blurring of boundaries that occurs within these MR worlds, the term Extended Reality (XR) has emerged as a way of describing these collective virtual realities, which blend digital and physical to create a new kind of spatial experience. It is not just that these technologies could replicate or replace tennis or football, but that they could take the essential qualities of these games and extend them into some new realm of physical experience that blends the best of physical and digital possibilities. For this reason, we will utilize XR to capture the range of new, digital immersive experiences that are beginning to be deployed around sports participation.

3 XR and Sports Fan Engagement

Sports clubs and broadcasters have already developed XR strategies, broadcasting matches, and creating virtual experiences for fans, but it is still early on in their development. For example, at the Rio 2016 Olympic Games, the Olympic Broadcasting Service experimented with broadcasting within a VR environment, allowing fans to watch the games, as if they were in the stadia. Central to this endeavor was the growing use of 360-degree film making, which is intimately connected to the possibility of creating virtual realities based on existing physical realities. Indeed, such experimentation is integral to the logic of the media industries, where innovation with new formats of content creation is critical to the ability of organizations to position themselves as market leaders in their industry's innovation economy. For instance, when Intel created a world record-breaking drone display at the PyeongChang 2018 Olympic Winter Games, it did more than realize a new creative spectacle. Rather, it positioned itself as a pioneering technology innovator, demonstrating a set of values closely aligned to its wider ambitions as an organization.

Sports clubs also show an increasing interest in using digital technology to create engaging and novel experiences in order to form connections with fans from around the world. XR offers a digital platform that can provide even more compelling experiences of the sports world through greater degrees of immersion. Through these platforms, fans are brought closer to live action, as if they are present in the field of play. Those experimenting with XR can now reach new fans and start to understand more about which types of content work best with the medium.

In this sense, new technology is a gateway into new forms of consumption. A good example of such desires to occupy new technological experiences that permit access to worlds that were previously unavailable is found in Jaunt VR, which showcased The VR 360 experience with Manchester City Football Club during match days. The experience included exclusive access to the players' changing room and a first-hand look at the players as they arrive on the blue carpet. The experience received over 1 million views in the first few days after release:

> There's nothing that compares with attending a match at the Etihad Stadium, but the emergence of 360 video and VR has allowed us to capture some of that atmosphere and excitement in ways that weren't possible in the past. (Diego Gigliani, City Football Group)

Alternatively, in boxing, a team working with Floyd Mayweather produced a "Boxing + Fitness" VR extension to his gym franchise that allowed users to train and even step into the ring with the former World Champion in VR. In the US, baseball has also had great success with VR by bringing the players closer to the fans. For example, the San Francisco Giants produced a series of VR videos allowing fans to experience the game from the players' perspective: "This is the price of admission right here. Watching Buster Posey catching in the back, a foul ball. You feel like you're in the game," explained 74-year-old Giants fan Mike McKay.

Most recently, FIFA and their broadcasting partners used VR in the 2018 World Cup in Russia. The BBC produced a VR World Cup smartphone app that was downloaded 325,000 times, which allowed fans to experience the action from three different angles. The app received mixed reviews but was considered a good start toward virtual fandom in the next World Cup. Some fans found the app hard to download and matches were broadcast in VR after the event.

These experiments with VR are situated within a long tradition of the sports media's continual investment into new technologies to make remote sports fan experiences ever more exciting. For some years now, billions of sports fans have been interacting on social media platforms such as Twitter, Instagram, and Facebook; and the most successful examples work because they bring the fan closer to the action and players. This is particularly evident in the way that social media giants like Facebook or Twitter have sought to occupy the live market: increasingly broadcasting sports content as it happens. These aspirations now extend into VR as the new market for sports experiences and organizations at the center of digital innovation are signaling their interest in this new experience economy. For example, Facebook is moving from two-dimensional social media and apps towards 3D virtual experiences through their acquisition of Oculus Rift and the creation of Facebook Spaces in 2014 (Dredge, 2014). Facebook founder Mark Zuckerberg emphasized the expectations for XR to dominate the future, "One day, we believe this kind of immersive, augmented reality will become a part of daily life for billions of people."

Sport is already playing a massive role in the integration of social media from 2D to XR experiences. For example, in September 2019, Sony Interactive Entertainment received a worldwide patent award for a VR, live audience experience in esports that allows spectators to enjoy esport events in VR from within a stadium or outside of it, thus creating a social VR experience (Sony Interactive Entertainment LLC 2019). Unique to this proposition is that the esports playing field is already digital, unlike traditional sports that are played on physical playing fields. Thus, re-rendering the content into a three-dimensional experience may herald a kind of audience experience that goes far beyond what is presently achieved; it may even create new forms of game play and expertise. Today's League of Legends world champion may not have the same kind of skill base as a VR League of Legends version; this could be a game changer for the industry.

Sports clubs have also used AR to engage fans in a range of ways, most often through an official club smartphone application. For example, a fan may use an app on their phone that, when positioned over a printed matchday program or a poster of a favorite player, will play a video of the player talking to you, perhaps with the latest matchday information. Systems exist to allow sports clubs to upload images and video to make this happen, making traditional printed material into more exciting, updated, and real-world social experiences. Likewise, the ability to overlay sports video or videos of players on fan photographs shareable on social media is another tactic that clubs, such as Bayern Munich, utilize to grow their respective brands:

> [With] FC Bayern App, visitors can now bring the painted fan motifs on kiosks to life. Dive into the year 1932, for example, when FC Bayern won their first German championship under then-president Kurt Landauer. Or into 2013, the year of the treble triumph with Jupp Heynckes. It's all made possible by a new augmented reality function that can be found in the FC Bayern app (FC Bayern Munich 2018).

Technologies such as the Virtual Hybrid Digiboard have been implemented in matches to allow worldwide audiences to experience the broadcast of matches differently. For example, the technology enables different, localized advertisements to be shown on the advertising boards and hoardings (Gray 2018). AR also offers potential for eCommerce solutions for sports clubs to sell merchandise to fans. For example, rather than seeing a photograph or video of a new sports shirt, the technology could allow that object or shirt to appear in 3D in a fan's home or even superimposed onto his or her person. Digital fashion pioneers, ASOS, demonstrated just that with their first AR fashion feature, which allows a virtual preview of fashion products overlaid onto the buyer (Whiteman-Stone 2019).

Also, in a compelling example of the convergence of esports, major events, and alternate reality technologies, an augmented reality dragon appeared in the stadium at the 2017 League of Legends World Championships finals in Beijing (Hill 2018; Biomajor and Oniatserj 2017). This format was replicated in the 2019 opening event of the Korean Baseball league (Landers 2019).

As discussed, VR and AR are being used increasingly to engage fans of different ages from around the world, both remotely and in live events. MR is perhaps less common, but with the introduction of technologies such as Microsoft's HoloLens in 2016 and much improved HoloLens 2 in 2019, this has opened up a range of new possibilities. For example, imagine watching your favorite game on TV, but you can project the TV anywhere you like in your home. Stats could be overlaid over a real game where the potential for fan interactivity is also great. Indeed, this has already been shown in various sports, including Major League Baseball with its "At Bat" mobile app, which allows "fans to point their iPhone or iPad at the field during a game and view overlay of 3D graphics displayed on top of the live view" (Hopper 2018).

4 Challenges for XR in Sports

Still in its infancy, one of the key risks affecting widespread adoption of XR is the potential loss that may follow from reducing the rich, social experiences that sports audiences currently enjoy, to a wholly insulated and individual virtual interface. So far, the virtual experience is mostly enjoyed experienced through an enclosed headset, without much opportunity for social interaction. For example, smartphone-only applications do not always offer a particularly social experience and are often discussed as notoriously anti-social devices in some contexts. Moreover, new interfaces are a risky business, especially when seeking to create a product that will be adopted as a mainstream, lifestyle experience, as it may serve to undermine what is already working about the sports spectator activity. Although the ease and comfort of VR headsets is improving and their prices are dropping, they can still be relatively expensive, uncomfortable, and disorientating. They can also create a sense of isolation from the broader collective experience that the typical live, sports audience experience (Torres 2016).

There are also technical limitations with headsets, such as the parsing of data and processing power to create an accurate, virtual re-creation of the speed and buzz of sports, especially live experiences. If the XR experience fails to meet the user experience of what it feels like to be present in physical space—for example, if the content judders or fails to load—then, not only is the experience diminished, but it can cause the user to feel disorientated, sick, or disillusioned. Therefore, XR experiences need to be implemented with clear comprehension of what is technically feasible and what users can tolerate. Plunging fans into new and unfamiliar virtual environments may cause unintended consequences of neurological disorder, anxiety, and epilepsy (Dredge 2016).

However, technology and immersive experiences continue to improve and, like any other creative media, they will become even more compelling and likely to establish a critical mass of an audience who seek out such experiences. Yet, it is also true that people's expectations of immersive experience changes over time. For almost every iteration of the history of gaming technology, proximity to the real has been a continual narrative. Each iteration of a game console achieves higher and higher degrees of realism and hyper-realism, even when graphically—looking back now—things were quite primitive. This teaches us that people's perception of realness also shifts over time.

At this stage of technological development, sports find themselves at a crossroads with regard to their use of immerse media experiences. While there is a critical mass of content creators that are experimenting with new forms of VR, AR, or XR, there is yet to be a large audience willing to invest into such consumer experiences, which leaves development vulnerable. As with any new technology, there is a period of time where it shifts either from innovation to obscurity or to becoming a worldwide phenomenon for enough consumers to justify the investment. Yet, what is interesting about these new experiences is the proposition that they may yet replace present-day flat-screen content.

5 Virtual Fan Experiences

So far, we have seen that sports clubs are willing to experiment with XR technologies for fan engagement. For instance, a growing phenomenon is that of creating social virtual fan experiences. For example, Liverpool Football Club integrated VR into their Anfield stadium experience and took this interactive experience on tour to Mumbai and Jakarta. The technology allowed fans to experience scoring a goal in front of their home stand, with thousands of Liverpool fans watching (Liverpool FC 2018). The design of such experiences is not entirely new. Sports clubs have a longer history of using large screens to create virtual matchday experiences; this could be in a stadium, a large public area, or even a cinema. As projector and screen technology improves, this opens up potential for even more immersive video to create more engaging virtual experiences for fans. This approach could overcome some of the issues associated with VR headsets while retaining the social element of being with other fans within a simulated virtual environment. For example, a 360-degree video of a sports match could be projected into a physical space and spectators could recreate some of the best things about the matchday experience in a more virtual sense. This could be done within a circular room, an inflatable dome, or any space that could be used for live matches, classic matches, or even esports in different cities of the world.

The potential to integrate other technologies and create a second screen experience opens up a myriad of opportunities for interactive and personalized virtual fan experiences, transcending boundaries, and building bonds with an international and more diverse fanbase. For example, virtual fan experiences open up potential for different groups of younger people (generation Z) or groups that might not feel comfortable in a stadium environment. Consuming sport, therefore, through carefully designed and personalized virtual fan experiences opens up potential to widen the fanbase on a global scale. It also creates opportunities to see, feel, and hear things that would not be possible in the physical world.

6 XR for Players and Performance

In some respects, the creation of virtual realities has long been a performance development tool within elite sports. For decades, sports scientists have sought to simulate the sporting arena to more effectively analyze athletes' performance and better prepare them for competition. For example, ahead of the Nagano 1998 Olympic Winter Games, the US Bobsled team used a VR simulator to prepare for competition (Huffman and Hubbard 1996). Additionally, such devices as rowing simulators and even exercise machines are forms of simulation that are intimately connected to the development of digital simulations. Today, simulation is a big part of the sports science and engineering research base and encompasses a range of technological tools—from the creation of wind tunnels to the invention of entirely new sports as VR activities. The desire to simulate the sports arena is deeply embedded within the logic of sports science in order to devise even more sophisticated training techniques and insights that can increase an athlete's competitive advantage.

The integration of simulation and digital virtual realities is where some of the most compelling propositions are found. For instance, STRIVR provides VR training for soccer players, especially to assist in the mental preparation for competition (Rettig 2017). Craig (2013) reveals how such technologies can assist players in understanding what is required of them in competition, particularly around cognitive demands. In this sense, it is not simply in the replication of the competition environment where VR may be used to better prepare athletes for competition, but in the creation of various tests where skills may be developed and subsequently applied in the sports setting. Alternatively, VR may be utilized to create more effective rehabilitation exercises for athletes after injury, as indicated by Goekler et al. (2016). Or, the major gains from VR may simply be in providing a more effective means to achieve some competency goal. For instance, when using video with VR as a training system for handball goalkeepers, Vignais et al. (2015) discovered that it can be a more realistic and effective way to train visual perception in players.

Virtual realities are also creating new forms of performance experience, which go beyond simply trying to improve performances through insights achieved in training. For example, Project Arena (2016), a HTC Vive experience, takes the gesture-based actions of hand controllers and transforms them into a game that requires the skills needed for tennis, but is played in digital, virtual space, and fantasy-based arenas. Alternatively, VR is already being used to play entirely new sports. For example, in 2018, HADO esports launched games that use VR headsets to create a social, competitive sports experience within a physical arena. In one case, four players—two versus two—battle against each other using headsets and mobile controllers in virtual and physical space.

AR is increasingly being used to develop performance data, most recently with the launch of a collaboration between worldwide sports sponsors Alibaba and Intel. Their new platform will permit a real-time, artificially intelligent, 3D tracking, which can analyze an athlete's performance; it is intended for launch at the Tokyo 2020 Olympic Games (Sharma 2019). One of the key dimensions of these technological innovations is how business partners are expanding their own category of interest associated with the sports. For example, one of the longest serving sports sponsors, Coca-Cola, is now a long-standing esports sponsor and even has its own YouTube esports program produced in partnership with game and entertainment platform IGN (Coca-Cola 2015). Thus, what may previously have been seen as simply a beverage provider is now also, increasingly, occupying the space of a broadcaster and technology service.

7 Conclusion: The Future of XR in Sports

Sports find a great deal of common ground with digital VR experiences since both involve the creation of new worlds. Yet, this commonality is not unique to sports and much early work exploring virtual realities wrote also of its wider relationship to theatre and its various derivative forms, like film or television. Yet, sports are distinct contexts for applied VR and warrant special attention, in part because they are also packed as highly mediated experiences, economically dependent on the orchestration of vast media networks, which mobilize to report on the events as they occur in physical space. In this respect, the history of sports broadcasting and media leads inexorably to experimentation with virtual sports experiences, as sports media has always sought to find ways of integrating new media technologies within their wider economic infrastructure. As Sankar "Jay" Jayaram from Intel Sports notes, "We believe that immersive, interactive, personalized experiences are going to define the next wave of how fans experience sports–and that that's what we are focusing on" (Beer 2019).

There are a number of technological and cultural trajectories that influence the uptake of virtual sports today; central among them is the integration of XR experiences, which cuts across the athlete's performance experience as well as the spectator's enjoyment of the activity. One influential parameter within this configuration is the shift towards the expansion of esports to the world of VR. Through such integration, the world of sport continues to blur its boundaries with the world of competitive computer game playing. While the inclusion of VR sports in the Olympic Games may not arise until Paris 2028, that prospect seems far closer today than it did even four years ago, when the technology that could make such experiences possible was not yet available.

Looking ahead even further, new kinds of physical activities are emerging through the integration of digital technologies within exercising and competition experiences. Already, sports stadia are being reconfigured through the increased use of interactive objects and surfaces, which emerge out of the new applied field of media architecture. Examples of such radical designs are found in the work of pioneering architect firm Populous, which created the world's first esports stadia in 2019 (Hayward 2019).

Additionally, the rise of playable spectator experiences will see increasing uses of active participation that will traverse arenas, as temples of the latest technological simulators. Yet, it will also include the integration of live-sports events and digital gaming components with next-generation gymnasia. Even here, the recent history of the gym has shown the growing utilization of gamified exercise components. In 2019, we see the manifestation of this in the form of competitive virtual cycling launched by Zwift, which now has its own international competition (Ballinger 2019).

The merging of fantasy and physical sports is also likely to grow, the appeal of which is a growing capacity to restrict and control the unpredictable elements of the theatre of sports. In this respect, there is a growing desire for sports event owners to minimize the unpredictability of their products, by subjecting all of its components to common contracts. Again, here, we see how esports are championing such principles, compelling its players to participate within their terms of reference and limiting their capacity to operate as a labor force (Holden and Baker 2019). These are not necessarily desirable features of sport's future and so are important to guard against.

The future of sports may be most adequately described by the integration of increasingly digital immersive integrations, where virtual realities promise a more dynamic and enriched form of sports than is presently achieved. An important component of this is the manner in which the amateur experience also converges around this virtual space. XR has the potential to bring a more integrated participatory experience to support spectatorship, which means spectators need not simply sit and watch but can actively participate through their own physical activity. The future of elite sport experiences is not just watchable but is also playable.

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Video Games, Technology, and Sport: The Future Is Interactive, Immersive, and Adaptive

Johanna Pirker

Abstract

While traditional sport spectator numbers decline, the number of viewers in interactive media such as streaming platforms, video games, and esports continue to increase. In response, Pirker offers a characterization of the new generation of consumers and the technologies opening up new avenues for engaging and immersive experiences. She demonstrates that with the help of virtual reality (VR), augmented reality (AR), and artificial intelligence (AI), among other technologies, traditional sports can follow successful strategies from interactive media. But the influence is not one-sided. Pirker also offers a picture of the two-way relationship between sports and videogames and how both industries might develop as technologies improve.

1 Introduction

There is a significant decline in interest in traditional live sports. Every year, the number of spectators in sport decreases; traditional TV stations struggle with declining ratings and an aging audience (Singer 2017). But why? The answer: Generational change. Particularly when we look at the new generations, we see new consumer behavior, expectations, and needs. For example, Generation Z doesn't know a world without the internet, smartphones, and flexible and personalized forms of entertainment. They are digital natives who grew up in a world that is interactive, adaptable, and fast-moving. As a generation, they require interactivity and personalization. They don't want to be passively consuming media; they want

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to be part of the experience (William 2015; Beall 2016; Northeastern 2014). Traditional TV programs are not flexible enough; so, on-demand and personalized services such as Youtube or Netflix, and interactive formats like Twitch are taking their place.

While many industries are currently suffering from a decrease in audience numbers and ratings, one industry generates more revenue than the digital film industry, the music industry, and the book industry combined: the video game industry. A game like Rockstar Games' *Grand Theft Auto (GTA)* generates more revenue than a Hollywood blockbuster like *Star Wars* (Mitic 2019).

Games are interactive, immersive, and actively involve the users. The fascination with games is multifaceted—they draw users into virtual worlds and engage them for hours. But it is not just the players who enjoy the interactive nature of games. Through services like Twitch, spectators are increasingly involved in the gaming experience (even though they're watching not playing).

The video game industry plays a major role in the development of innovative technologies and pioneers' new products that push boundaries for exciting gaming experiences (ESA 2013). For example, technologies such as virtual reality displays offer even more engaging and immersive experiences; they allow more realistic and innovative forms of entertainment and virtual interaction. Users can participate in comprehensive and realistic experiences without leaving the living room (Dede 2009).

Three factors—interaction, engagement, and immersion—seem to be critical drivers of successful media formats such as games and streaming services. In contrast to these interactive, personalized, and fast-paced forms of media, traditional sports seem slow and passive. So, what can we learn from video games, esports, live-streaming services, and immersive technologies to make the future of traditional sport more interactive and motivating? The answer to this and similar questions will be discussed in this chapter; I will also outline a potential future for traditional sport in terms of audience participation, immersive sports experiences, and interactivity.

2 The Role of Interactive Media in Sport

The video game industry, and gamers especially, struggle with several prejudices; for example, some would imagine the typical gamer as a young man playing shooter games alone in the basement all night. However, the number of gaming enthusiasts is large, and gamers are diverse. In America, for example, 65% of adults play video games, 46% of gamers are female, and the average age is 33 years old. They enjoy social gaming experiences; and 63% of adult gamers play with others. Gamers are also probably closer to the world of sports and have more in common with athletes than one would think. They are more likely to exercise (average 4.1 h/week) than average Americans (3.9 h/week). They like games that involve competitive elements as shown by the popularity of certain games; sport and racing games are among the most popular genres at 11.1% and 5.8% of sales, respectively (ESA 2019). The sports games *NBA 2k19* and *Madden NFL19* were among the five best-selling video games of 2018. Millennial gamers (between 18 and 34 years of age) and Gen X gamers (between 35 and 54 years of age), in particular, name sports and racing games like *Forza*, *NBA 2 K*, and *Madden NFL* as their favorite game.

Video games and simulator experiences have always been inspired by traditional sport experiences; and many of the highest-selling games are sport-based games (Arshad 2014). Video game series such as EA Sports' *FIFA*, *NBA Live*, *Need For Speed*, *F1 2019*, and *Pro Evolution Soccer* have accompanied real sports competitions. These games emulate playing traditional sports and are often popular because the sport itself is popular. They offer non-professional athletes the opportunity to participate in tournaments, drive the fastest cars, or even play on the green of the Bernabeu Stadium.

Video games not only offer the opportunity to simulate real sports, but also make it possible to create sports experiences that would not be possible in real life. One early example is the video game *Speedball* (The Bitmap Brother 1988), a futuristic and violent cyberpunk sports game that brings together elements of handball and ice hockey. Psyonix's *Rocket League* is currently the most prominent example. It combines two popular sports: soccer and car racing; two teams face off in rocket-powered cars to hit a ball into a goal. In 2018, more than 50 million players were counted (De Meo 2018). The fan community is vast; and tournaments and world cups are organized just like traditional sporting events. Both examples demonstrate that sport is an essential inspiration for the digital world. In addition, the digital world offers opportunities to create fictional forms of sports virtually that would otherwise be too dangerous or impossible.

But it is not just sport that shapes the digital world. The digital world also increasingly influences the world of sport. For example, skateboarding was not known to many for a long time; through a video game, the sport has been introduced to millions of children who'd never skated before. Children suddenly talked about their favorite moves in typical skate terms and knew relevant brands, athletes, and even corresponding cultural aspects like music. The game quickly turned a marginal sport into a trendy one, pushing skateboarding into the mainstream and inspiring young gamers to become athletes (Ombler 2019).

Sports-based games are also commonly associated with sports. They have professional competitions and are an increasingly important market and form of audience entertainment for the new generation. The FIFA eWorld Cup, officially held by FIFA and EA Sports, for instance, is the world's largest video game tournament (Strudwick 2014). The Grand Final of the FIFA eWorld Cup 2019 generated record viewership—online viewership increased by 60% from 29 million views in 2018 to 47 million views in 2019 (FIFA.com 2019). Esport viewership is expected to hit 84 million in 2021. These numbers outperform sports leagues like the NBA and NHL (MBA Syracuse 2019) and demonstrate that we have to pay attention to this relatively young, but extremely fast-growing industry; we must seize opportunities to learn from successful strategies of spectator integration and motivation to revive traditional spectator experiences in sports.

For example, the video game industry has optimized the creation of engaging experiences for gamers *and* for spectators. With services like the Amazon-owed streaming service Twitch, people can watch other people play video games. Through a chat function, the platform allows social interaction with other spectators and the streamer/player and the option to impact the game through commands.

Understanding the current trends in the video games industry, such as interactive audience engagement, can give us insight into how the future of sport competition from the spectator's point of view could be.

3 The Future of Audience Experiences

Interactivity and involvement separate digital from spectator experiences of traditional games. Traditional sporting events currently leave little room for interaction between athletes and spectators. While the athlete performs, spectators can, at most, cheer and encourage. But this is reconsidered in the digital industry where viewers are increasingly able to be part of the game. In this section, we take a look at how current trends in the game industry shape the spectator experience and how this can influence the future of spectator involvement and engagement in sports.

3.1 The Active Spectator

"What's your favorite sport?" If you ask this question today, the answer for sports enthusiasts is often not the sport they themselves practice, but the one they like to watch. We can observe a similar phenomenon in the world of digital games. More and more people prefer to follow other players as they play a game rather than playing themselves. Classic esports events draw spectators from all over the world to real stadiums to watch their favorite players. People also use interactive live TV like Twitch to watch players and talk to others. Using alternative platforms to show digital gaming experiences enables various opportunities. Spectators have access to additional information and data about the game, the players, and the match. For instance, spectators can see the whole map of a competition, the perspective of every single player, and access information about specific strategies players choose for the game. This information availability creates new and interesting spectator scenarios and the chance for personalization. Various graphical user interfaces enable the spectator to arrange individualized spectator interfaces (Pirker and Angermann 2019).

Trends like interactive streaming also influence the development process. Video games are no longer designed just for the player; they also contain game elements that make them more interesting for streamers and spectators. The behavior and motives for spectating in sports and video games are similar and include elements like identifying with players, enjoying the aesthetic of the game/play and the excitement and drama of a match, gaining knowledge from the players' skills, interacting with other spectators, belonging to a group, and supporting a specific team or a player (Pirker and Angermann 2019; Matsuoka 2014; Alonso Dos Santos and Montoro Rios 2016). But what differentiates video game spectating and traditional sport spectating is the level of interactivity and the options to gain access to additional information.

Video game spectating is an increasingly important aspect of the video game industry. Twitch and similar players are essential marketing platforms for the companies and interesting streaming experiences are crucial for the sale of the games. Active interactions between players and spectators, spectators and the game, and spectators and other spectators are already part of the video game design process. Typical activities to involve and engage spectators are chat inputs, polling, cheering, and game modification (Mirza-Babaei 2018; Stahlke et al. 2018).

What we already see in video games is a new way of interacting and engaging with audiences. The future of sport spectating can be interactive too. With wearables, athletes' data can be available to the spectator thereby decreasing the space between the athlete and the spectator. In the next sections, three main technologies that can impact the experiences of both the spectator and the athlete will be discussed: (1) interactive sport experience and streaming services, (2) virtual reality technologies, and (3) augmented reality (AR) technologies.

3.2 Democratization of Sport Spectating

What is currently state-of-the-art for the computer games industry—a data-based and individualized spectator experience—may become normal for sports broadcasting in the future. More real-time data of athletes will be collected. More cameras will be installed in stadiums. Action-cams and 360° cameras will make it possible to take on the perspective of a favorite athlete, for instance. Through open data interfaces, different users will be able to access the data. This will give viewers the ability to follow individualized information and camera angles on their own displays. With open access to the video data and additional available information about athletes, a movement like a democratization of the spectator experience will be created. Every user can arrange their own displays with several information points, visualizations, chat interactions, and camera angles.

This, however, could also lead to an information overload. On one side, moderators will access various data channels and curate content to offer more specialized channels. On the other side, artificial intelligence (AI)-based processes will be used to automate and personalize the experiences. Through AI-methods it is possible to design individual viewer experiences based on preferences and past interaction data. For example, a Ronaldo-fan can watch the game with more camera views of Ronaldo while chatting to all Ronaldo-fans watching the game.

More spectator involvements and interactions are possible. In a video game, spectators can cheer for their favorite player who get, as a result, a specific in-game reward like a better weapon or an extra life. This system already works in the games industry and is starting to influence the sports industry. With new interfaces to the sport experience, it is also possible for spectators to influence competitions or even the athletes. For example, this has already been implemented is the Formula E race fanboost system. Here, users vote for their favorite drivers to give them an extra power burst (Formula E Fanboost 2020). Future scenarios could also include voting for referee decisions, rewards or punishment for athletes or teams, or even the support of players through advice from the audience. Through these interactions, spectators and athletes will get closer and more personal bonds will develop.

With the introduction of new hardware, even more options to gather data and forms of experiences can be explored, particularly with AR and VR technologies.

4 Playing with Reality

4.1 Augmented and Diminished Reality

Augmented reality (AR) offers new possibilities for athletes to optimize their training and sports performance, improve skills, and reduce the risk of injury through additional information. For example, smart ski goggles can already provide athletes with information about the course or their performance by displaying speed or suggesting a more optimal route. These use cases and many others have been explored by various studies and showcases.

Technologies such as AR could also offer new opportunities to engage spectators in live-sport events. AR glasses could make it possible to expand reality. Spectators could sit in a stadium and see elements of the playing field (for example, the offside line), names, and data of otherwise invisible players.

One option not often discussed is the use of such technologies to diminish reality. AR applications are mostly designed to display additional information and objects. However, the same technology can also be used to reduce or change the content visible in reality. Faces can be blurred, advertisements can be blackened, and objects disappeared. What if, for example, after a foul, the soccer player is penalized with limited vision?

AR devices offer several interesting possibilities for athletes and for spectators. However, current AR devices such as Microsoft's HoloLens or the MagicLeap are still expensive and uncomfortable to wear. They will not find a way into the mainstream until the technology is cost-effective and more accessible (Augmented Reality in Sports 2019). Particularly intriguing is the introduction of technologies like smart contact lenses, which could revolutionize the possibilities of augmented (and diminished) reality in the field of sports for athletes and spectators.

4.2 Beyond the Sidelines

Virtual reality (VR) headsets enable wearers to immerse themselves in a virtual space. They can experience things that are otherwise impossible, too expensive, or too dangerous. For example, VR itself is not an invention. The potential of virtual spaces, which can be quickly entered with head-mounted-displays (HMDs), has been extensively researched over the last 40 years in various disciplines (Freina and Ott 2015; Bruce and Regenbrecht 2009).

For athletes, VR already offers incredible possibilities; and the number of application scenarios will grow as VR headsets become more accessible and lightweight. VR training is already used for football training at Stanford University (VR training make Stanford kicker a hero: Strivr testimonial 2016). Researchers were able to show that this form of virtual training is an effective and immersive form of learning; thereby athletes can prepare themselves for competition through more personalized, cost-effective, and flexible forms of training. Opportunities will increase with future hardware improvements—for example, imagine systems that not only allow users to *see* the virtual reality but also to *feel* elements of the experiences through haptic feedback and more natural ways to interact with the experience (e.g. gloves, bodysuits).

VR is also a great way to enable spectators to be part of the experience. For the spectator or a non-athlete, VR can be a tool to better understand the sport, to be part of a sport experience without participating, and to play through realistic simulations that are often too expensive (e.g. driving a race car), too dangerous (e.g. base jumping), or impossible (e.g. flying without additional equipment). Also, through VR, the spectator better understands the point of view of the athlete. The spectator can replay a situation from the goalkeeper's perspective and see why he or she did not stop the ball. In skiing, for example, it is often difficult to understand speed, the height of the jumps, or the steepness of the terrain with a flat camera setting. VR allows the viewer to sit on the shoulders of Tyrol's Hahnenkamm and understand the real danger of a specific race. For the spectator, VR is a big and realistic chance to make sport more attractive, accessible, and engaging.

In a more distant future, VR could also enable real athletes and sportsmen to compete with athletes from the digital world. New sport experiences can be created and entirely new sport genres invented.

5 When Gamers Become Athletes and Athletes Become Players

The sports games and digital sports simulations have reached a peak of realism. In combination with smart devices such as indoor bike trainers, hardware vehicle simulators, and treadmills, various sports games can be performed not only visually but also physically from the living room. Here, we have to ask ourselves how much video games or sports simulations still differ from traditional sports.

Due to recent events, we are one step close to a fusion of these two worlds. In 2020, the coronavirus pandemic hit the world of professional sports. Most competition had to be canceled; and training was severely restricted as training in teams and any training with potential health risks (e.g. crashes with the bike) had to be stopped. The sports world had to look for new training and competition methods to minimize financial and sporting losses. So, the esports phenomenon spread to various traditional sports disciplines; and various online initiatives by sports associations were launched.

The eCycling League Austria, for instance, was launched as an online bike racing series (ÖRV 2020). The competitions are open not only to professionals but to all cycling enthusiasts with the required equipment, a smart indoor bike trainer with heart rate and watt power measurement. In this case, the bike represents the game controller. In this series, gamers have the chance to compete with professional athletes.

Also, Formula 1 launched the F1 Esports Virtual Grand Prix series as a virtual alternative to their races (Formula 1 2020). The races are broadcast on typical esports channels such as Twitch, Facebook, or YouTube. As a platform, Codemasters' official F1 2019 PC video game is used, and current F1 drivers are becoming gamers. This is not only a good way to entertain Formula 1 fans, but also to get people interested in the sport even after the competition restrictions are over.

In the future, more sports devices and sensors will enable the physical execution of various sports at home or in special studios and connect realistic sports simulations and games. In combination with VR, an even more realistic experience will be enabled. With the help of such realistic setups, it is possible for athletes to compete against each other regardless of their physical location. On top of that, it will also allow non-professional athletes—gamers—to compete with top athletes.

6 The Future of Games

The games industry has driven many significant technological advancements including important innovations in hardware such as capable graphic processing units, AI research, software tools such as powerful game engines, and spectator experiences, VR, and AR. It is clear that the future of games will revolve around major technological leaps.

Virtual and augmented reality will be an essential element of the future of video games. VR experiences can create entirely new and fully immersive game experiences. But this also requires new game design guidelines. In VR games, users usually play the game through a first-person view. As a result, more games will be created as first-person games. In most successful sports games, the player sees a view similar to TV broadcasts (soccer games, NHL, NBA, skateboarding). Few games are currently played from the first-person perspective (racing, cycling), though they do allow players to become athletes with the associated smart training equipment. Because of VR, the future will bring more first-person sports experiences and complementary equipment to players. For example, imagine a VR climbing experience combined with a tread wall for climbers or a VR New York city marathon combined with a treadmill for runners.

Video games will become increasingly adaptive and personalized. With data analysis, games can be adapted automatically to specific play styles, player types, or the skills of a player. This will enable full engagement and optimize the effect of the training. Such personalized experiences will also impact digital sports experiences. A Formula 1 pilot can train engagingly with the help of a smart AI-based ghost system, which instructs the pilot in a personalized way to find the ideal line. Also, game engines will be increasingly advanced and influential in the future. Game engines are the software tools used to create games. Since the release of free and user-friendly game engines such as Unity or Unreal Engine, the development process has become more accessible and open to a larger user group. Some game engines enable the creation of games without game development or programming knowledge. Architects can use game engines to plan buildings, archeologists can recreate archaeological sites, and historians can create virtual museums. Also, athletes will be able to develop their virtual training or VR marathon experience and share it with other enthusiasts around the world. In the future, the athlete will become not only a gamer, but also a game developer.

7 Conclusion

Following the video game industry, the future of sport holds many exciting possibilities. We already see the need for spectators not just to watch, but to interact directly and actively. Facilitated by interactive streaming services, video game spectators can interact with other spectators, the player, or the game itself. Future technologies will also enable spectators in sports to be involved more actively. This will also enable a stronger bond between spectators, the athletes, and the sports experiences.

Currently, game viewers can reward or punish players based on their performance. Similar developments are conceivable in the world of sport. While initial attempts have already been made in more technologically advanced sports such as racing (Formula E Fanboost), technological enhancements such as AR and VR can extend this possibility to traditional sports such as football or skiing. AR, for example, enables viewers to obtain extra information about the sports scene. On the one hand, this allows athletes various optimization possibilities (e.g. optimal driving lines when skiing), but it could also develop new sports scenarios by changing the viewpoint or shortening the scope of sight (for example, as a penalty for a foul).

These technologies also offer the possibility of personalization. The viewer can quickly elect the viewpoint of the striker, the referee, or the downhill skier by means of virtual reality. Enthusiasm and understanding of the sport and the performance of the athlete will increase; the spectator is right in the middle of the action and not just a passive part of the experience.

The future of the two industries—video games and sports—will be exciting and multifaceted, but not without many challenges. Collecting additional data will enable personalized sports and spectator experiences and advanced versions of the training. However, this also results in information and data overload. The digitalization of sports also opens more loopholes and opportunities for cheating. As a result, security experts and computer scientists will become a more integral part of sports organizations.

But, bringing the games and sports industry closer together will be beneficial for both. Among the benefits, gamers can be part of professional sports competitions from their living rooms and athletes can train and compete in a more flexible way independent of time and place. Realistic VR sports experiences will make sport experiences, which are otherwise impossible, too dangerous, or too expensive, accessible to everyone. Anyone with a VR setup and peripherals such as smart climbing mills can enjoy ascending Mount Everest from home. Although such experiences can be realistically simulated, they cannot replace the feeling of a real ascent, where the unexpected and the potential danger are an essential part of the experience. At least, not yet.

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Final

Impossible Sports

Brian Subirana and Garcia Jordi Laguarta

Abstract

To illustrate how future technologies will shape future sports, Subirana and Laguarta explore an imaginary future—following a fictional character and her family through a day in their lives. They highlight potential applications of technologies in the fields of the Internet of things, robotics and automation, information processing, communications, and legal programming in new sports. The chapter also explores potential sports that, beyond entertainment, could solve real-life problems or otherwise improve society with examples like improved human relationships with animals, increased safety from environmental dangers, and more efficient smart cities.

1 Introduction

Sport and technology have mutually promoted each other's development for decades. Innovations in technology made the creation of new sports possible and provide the tools to make sport better, safer, and more equitable. Windsurfing would not exist if it were not for the invention of the sail, nor Formula 1 and MotoGP without the motor; and ball sports like football, tennis, and basketball

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would still suffer from erroneous calls. In exchange, the sport has served as a catalyst for innovation in new technologies including many that propagated from professional use cases to fitness, wellness, and health.

Sports are more popular now than ever before and society looks to athletes as a guide for healthier lifestyles. This point, combined with what is just the beginning of a new technology revolution, inspires questions about what sports of the future will look like and what role they will play in shaping that future.

In this context, the present chapter focuses on nine distinct fields of technology that we believe will greatly progress in the coming decades and nine new "impossible" sports that they might give rise to. Although these impossible sports are just examples that might never become reality, they provide a glimpse at what new sports could be thanks to future technologies. The nine technological fields described in the chapter are grouped into three different domains: life, information, and matter.

2 Overview

This chapter invites you into an imaginary future; we follow Dr. Brown and her family through a day in their lives, illustrating many impossible sports made achievable by future technologies and their potential applications. In our imaginary future, the state of development of the internet of things (IoT), big data, and cybersecurity is much more mature than it is currently. The scenario is designed to explore the potential uses of technologies currently in varying stages of development—some may even be unattainable. The future scenario has been organized into nine groupings. The first three will focus on *Life*: artificial life, technology bringing "intelligence" to novel non-human life forms; sensing, health sensors and 3D navigation; and human interfaces, augmented reality (AR) interfaces for humans. The next three groupings will be centered around *Information*: processing, artificial intelligence (AI) reasoning and processing like humans; storage, information stored in a distributed, secure, and efficient manner; and networks, information sharing near and far. The final three groupings pivot around *Matter*: breathable matter, assembly tasks that until now only humans could do; high-resolution management, managing tiny quantiles of matter; and legal programming, technologies enabling new contracts, payments, and governance schemes. Figure 1 illustrates the nine broad groupings of technologies that will be explored throughout the chapter.

To illustrate their potential, every one of these nine groups of technologies is represented by a different impossible sport. Furthermore, each sport helps paint a picture of the role it will play in promoting innovation in a specific industry. Table 1 shows the sport-industry pairings and describes the value each technology will bring to its corresponding industry.

Fig. 1 Nine groups of technologies

3 7:30–8:30 AM: Artificial Life—AI Pet Companion Racing

Dr. Brown's dog, Muddy, is preparing to compete in the annual Dog Olympics, a contest that tests dogs' physical ability and intelligence through a set of tasks with their AI Companion. Dog racing evolved greatly in the past years as technology for animal interfacing made it possible for basic communication between dogs and AI systems. What once started as a smart collar to teach dogs simple habits and rules in the house, evolved to an AI companion, empowering dogs with utility and autonomy (Mancini et al. 2017) (Fig. 2).

As he begins his daily training, Muddy is given tasks to complete through alerts received in his feedback collar (Mancini et al. 2017). His first task is to pick up some groceries. His smart collar calculates the route to the nearest store and guides

Table 1 Summary of technologies with their corresponding sport and impact industry

Domain	Technology	Sport	Description	Industry
Life	Artificial life	AI pet companion racing	Intelligent interfaces for non-human life forms	Neuroscience
	Sensing	Calorie racing	Health sensors and 3D navigation	Health diagnostics
	Human interface	AR real-life soccer legends	AR interfaces for humans	Cyborgs
Information	Processing	Mental sports	AI reasoning and processing like humans	Artificial intelligence
	Storage	Ambulance racing	Information storage in a distributes, secure, and efficient manner	Smart cities
	Network	Avalanche hunting	Information sharing near and far	Telecommunications
Matter	Breathable matter	Emission free racing	Assembly tasks that until now only humans could do	Sustainable energy
	High-resolution mgmt	Warehouse escape	Managing tiny quantiles of mailer	Logistics and robotics
	Legal programming	Idle sports	Technology enabling new contracts, payments, and governance schemes	Digital banking

Muddy accordingly. The collar's 360° stereoscopic camera warns Muddy of any approaching cars as he crosses streets and allows Dr. Brown to keep a watchful eye on him (Golbeck and Neustaedter 2012). She isn't too concerned, though. Dr. Brown knows that if he were to veer too far off course, the collar's location tracking would trigger a geofence alert.

As Muddy reaches the convenience store, he receives further feedback through the collar directing him to the dog collection flap. He picks up the groceries and races home to drop them off. Next, he receives another alert from his feedback collar to race to the nearby beach and collect plastic waste for recycling. As he arrives at the beach, computer vision on his collar detects a plastic bottle nearby and guides Muddy to pick it up and drop it at the nearest recycling bin. After a job well done, he makes his way back home for a back rub.

4 9:45–11:45 AM: Sensing—Calorie Racing

Muddy arrives back home and is cleared for entry by the home defense system. As he walks into the living room, he finds Dr. Brown struggling as she tries to beat the neighborhood's Calorie Race record—a popular competition to lose the maximum

Fig. 2

number of calories in a given time. Made available by the innovation of high-precision sensors, Dr. Brown's calorie tracker detects relevant biomarkers and uses an algorithm to accurately measure the number of calories burnt. Her IoT personal trainer guides her through a personalized workout specific to her body's level of fitness and calorie aim, adapting in real-time based on feedback from her biosensors to maximize calorie loss (Konstantas 2007) (Fig. 3).

Just as Dr. Brown is finishing her final burpees, she receives an AR notification that a baby cot in the neighborhood has detected an arrhythmia in a baby's heart (Konstantas 2007). Dr. Brown runs out of the front door while looking over the baby's vital signs; her peripheral vision keeps track of the sidewalk's flashing emergency alert lights that guide her to the address of the unfolding emergency. Several drones are dispatched from the hyper-local clinic and arrive with the appropriate equipment for infant resuscitation including diluted adrenalin and other fluid preparations for just such an occasion. A local community self-driving car has repurposed itself to serve as an ambulance, tracks Dr. Brown, and picks her up to drive the last thousand yards to the address at bullet-train speed; all other vehicular traffic pauses to allow them to pass safely and easily.

Fig. 3 ©Brian Subirana. All rights reserved

5 12:30–1:30 PM: Human Interface—AR Real-Life Soccer Legends

As Dr. Brown and her son sit down for lunch, the robot assistant picks up the freshly squeezed juice from the other side of the kitchen and places a glass softly in front of her and a plastic cup in front of her son. The assistant leaves the room and Dr. Brown starts the family debrief with her daughter and son. Her daughter, who is studying abroad, is broadcasted from a projection drone hovering above the table as she shares her recent accomplishments in AR Real-life Soccer Legends (Azuma et al. 2001). The online sport consists of an AR version of soccer where users compete to improve their soccer level by playing against simulations of real world-class football players. As users start a new game, a combination of holographs displayed by projection drones turn a room into a soccer pitch (Bajura et al. 1992). Recorded movements from past games of current and retired professional soccer players are used to project real-life simulations onto the pitch. The technology has proven so realistic that real soccer teams play AR Soccer Legends to prepare for games and learn about the different teams they face (Fig. 4).

Dr. Brown's daughter shares with her family that she is ranked the best goalkeeper in her country, with the highest percentage of saved penalties from Messi and Maradona. Due to this merit, she has been offered the position of goalkeeper on her national team to compete in the AR Soccer Legends World Cup, a tournament that takes place in a virtual stadium where players and fans can join regardless of their location.

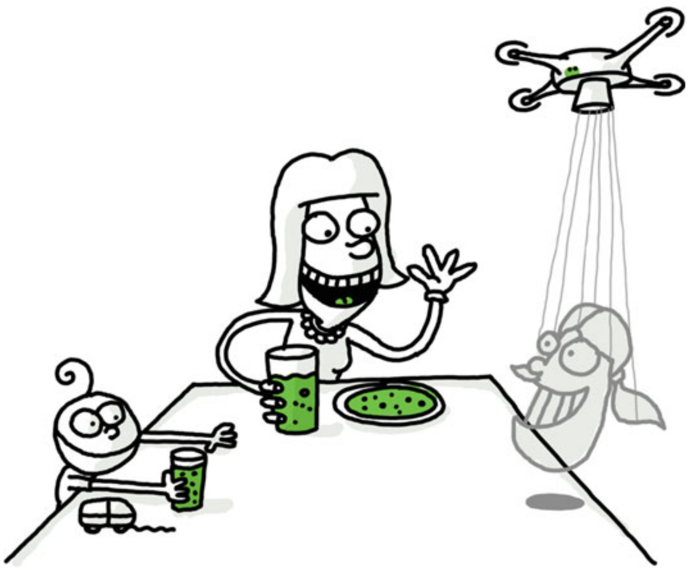

Fig. 4 ©Brian Subirana. All rights reserved

6 2–2:45 PM: Processing—Mental Sports

After Dr. Brown and Muddy finish their lunch, they head to a history museum in one of the community self-driving cars. On the way, her phone notifies her of a long delay on their route. Suddenly, her smartphone assistant turns on and suggests that this spare time could be put to good use by playing a few games of Mental Sports. Dr. Brown nods at her camera and her smartphone assistant opens the Mental Sports application. By processing Dr. Brown's interests, past conversations, and upcoming events, her assistant suggests a few categories that Dr. Brown might want to learn more about like mathematics, sports science, and history (Moor 2006). To prepare for her upcoming visit to the history museum, she chooses to brush up on history knowledge (Fig. 5).

Dr. Brown is paired up against her work friend, who is also a level four on General History and currently online. As the timer counts down, the Mental Sports AI searches the web for relevant information based on psychological analysis, past books read, and courses taken and prepares a question set. The questions are uniquely prepared for fair competition between the two (Baum et al. 2011). When both players are wrong, the solution is presented in a manner that is most suitable for the learning ability of each player, hence optimizing the knowledge they acquire (McArthur et al. 2005).

Fig. 5 ©Brian Subirana. All rights reserved

The self-driving car arrives in front of the history museum just as the intense competition ends and Dr. Brown and Muddy hop-off. Image recognition identifies Dr. Brown's face and automatically charges her bank account as they walk into the museum; she is eager to apply her newly acquired learnings and make the most of her museum experience.

7 4–5 PM: Storage—Ambulance Racing

Even in this distant future, fresh air is still appreciated after a long museum tour. Dr. Brown's IoT health assistant suggests that she walks part of her route home with Muddy. As she starts her walk, her shoes immediately start to capture, process, and relay tile status information from sensors in the sidewalk to a remote data store. Along with the overall environment status and maintenance data for the built environment, her personal stats are also uploaded for big data analysis (Fig. 6).

Stopped at a red light, Dr. Brown sees two ambulances rush by rapidly. She remembers that today is the annual Ambulance Race in the city—a competition that tests the fastest ambulance drivers in town. Ambulances race through the city—they must reach the hospital in the fastest way possible. They are penalized, however, for driving too dangerously and risking an accident. Dr. Brown does not worry though, an accident is unlikely to occur as all cars in the area coordinate through cloud avatars, sharing data in real-time to maximize flow and prevent accidents.

Made possible by advances in longitudinal databases, the smart city has collected and analyzed data on every intersection to streamline traffic. Speed limits no longer exist—something that would seem foolish years back. However, due to improvements in distributed data storage and sharing, driving accidents are now a thing of the past.

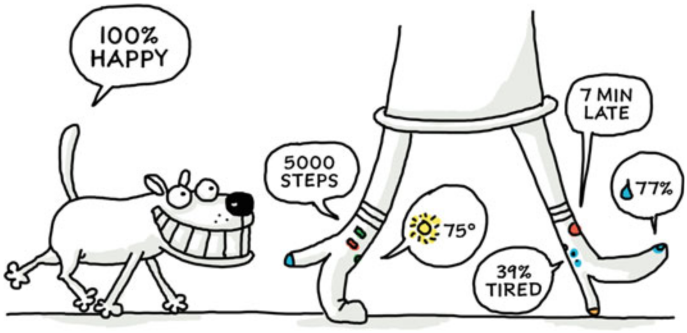

Fig. 6 ©Brian Subirana. All rights reserved

8 5:20–5:40 PM: Network—Avalanche Hunting

As Dr. Brown is on her way home, she consults her social networking app to see which relationships need attention. Her app indicates that she has not seen her friend Mike in some time and his house is on her way home. She calls to see if he is available; and he invites her over for coffee. Excited to the show Dr. Brown his SmartCook2029, his new robot cook, Mike—who is well known for loving his artisan coffee—uses precise hand gestures to guide the robot to obtain the optimum coffee to cream equilibrium. Dr. Brown places an order for her favorite protein salad (Fig. 7).

As they sit down, Mike describes a new sport called Avalanche Hunting for which he has become passionate recently. The sport consists of detecting and detonating accumulated snow that could lead to avalanches. By leaving low-power, long-range (LoRa) devices in steep mountain slopes, he can collect data on the snow conditions over years and communicate the information through a Mesh Network onto a cloud server (Adelantado et al. 2017). If Mike thinks that the conditions might lead to an avalanche in a certain area, he sends a drone to map out the area. Made possible by 5G, he can watch the drone footage with his virtual reality (VR) headset from home and simulate different detonation strategies to find the ideal method for that slope (Xiong et al. 2015).

Mike, who adores off-piste skiing, describes to Dr. Brown how Avalanche Hunting has not only helped him learn more about the conditions that cause avalanches and how to avoid them, but also makes him feel safer on his ski adventures.

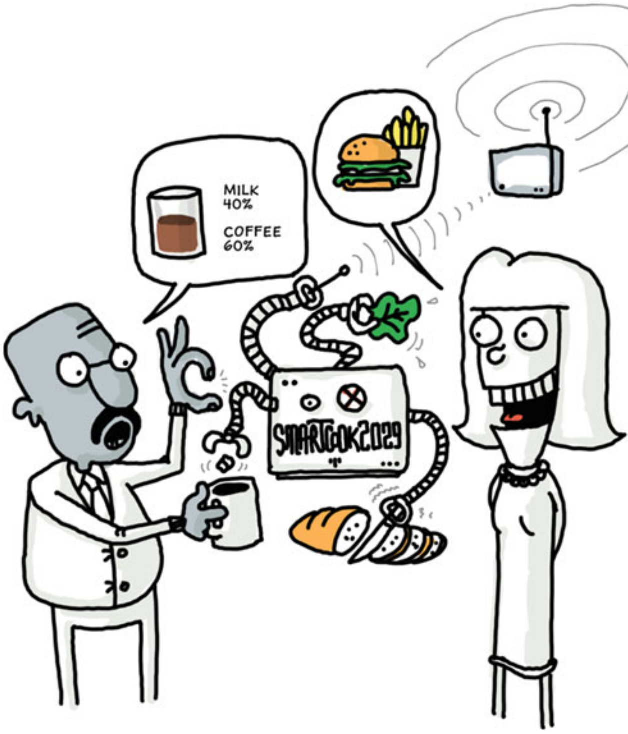

Fig. 7 ©Brian Subirana. All rights reserved

9 6-PM: Breathable Matter—Emission-Free Racing

Dr. Brown and Muddy prepare to watch the Emission Free Racing Championship, a race that has driven innovation in the field of breathable batteries. As they get in the community car to go to the stadium, she puts in an order for coffee and her favorite sandwich. On arrival, Dr. Brown exits the vehicle and walks up to the attendant robot. The robot walking by Muddy assesses his physiology and gives him a backrub. Dr. Brown confirms her coffee and sandwich order with the robot and payment is automatically charged to her account (Fig. 8).

The race is about to begin. Car teams are optimizing their strategy with respect to how many batteries to load. Too few could mean the electric car is not able to complete the whole race, but too many would make the car heavier and slower. The racecars are able to autonomously exchange batteries and leave used ones charging along the track with solar power to be picked up in future laps. Therefore, racers must factor into their energy management decisions the varying solar availability along the track throughout the race.

Fig. 8

Dr. Brown is fascinated by mechanic robots' fine manipulation of assembly tasks as they swiftly replace worn-out race car wheels during pit stops. Suddenly, two race cars collide on a turn leaving debris on the track. Drones quickly rush to the site and meticulously clear the area before the next cars pass by. As the race comes to a near end, the cars get rid of any unnecessary batteries stored in their trunks to gain a competitive edge over their opponents. The teams face important decisions as they try to minimize the batteries carried—too few could force the drivers to reduce their speed in order to reach the finish line.

10 7:10–8:30 PM: High Resolution Management—Warehouse Escape

Dr. Brown receives a notification on her smart watch that her favorite sports brand organized a Warehouse Escape—a challenge invented by sports companies for customers to try their new clothes while managing peak manual labor demand for picking and stowing items in their warehouses. In a gamified way, Muddy and Dr. Brown must run, climb, and jump through the warehouse's array of clothing as drones project holograms guiding her to pick up specific items and drop them off at specific locations or to throw them into other drones carrying bins. As Dr. Brown prepares to start, she is presented with a sample of sports clothes and running shoes to wear during the challenge (Fig. 9).

Several game modes are offered to Dr. Brown and she chooses her personal favorite: Jungle Escape. "Three, two, one, go!" Holograms of jungle animals projected by drones chase her and Muddy through the warehouse as she completes tasks; she is increasingly close to escaping the jungle-converted-warehouse for "safety." For her efforts, Dr. Brown is rewarded with customer loyalty points that can be exchanged for discounts and exclusive offers for that brand. On her way out, she receives the offer to keep the clothes and be charged automatically.

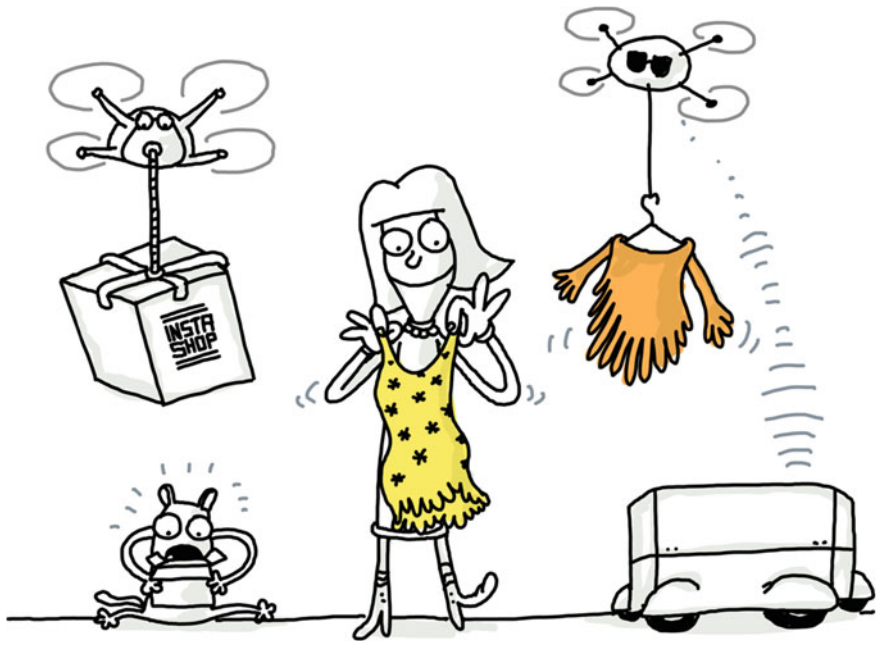

Fig. 9

As she walks back home, she sees that the store is putting together a pop-up shop on the other side of the road from boxes transported in the spare space of the trunks of the other community self-driving cars, continually monitored with RFID tags (Subirana et al. 2003). As she thinks, dresses in her size and preferred cut are pushed forward on the rail. By picking up the items, she triggers the proof of delivery and purchase. Payment is automatic, her loyalty points are exchanged for discounts, and the pending balance is collected on exit.

11 9–10 PM: Legal Programming—Idle Sports

After a great week of holidays, Dr. Brown makes it home. After saying goodnight to her son and Muddy she retires upstairs to review the household finances. Her IoT negotiation agent's holographic avatar appears and suggests changing the utility company to which she sells her health and sport activity data. Apparently, there is a great joining bonus for those with more than 35 years of sport activity history and more than three weekly sport sessions. Immediately after changing companies, her cryptocurrency balance is updated (Fig. 10).

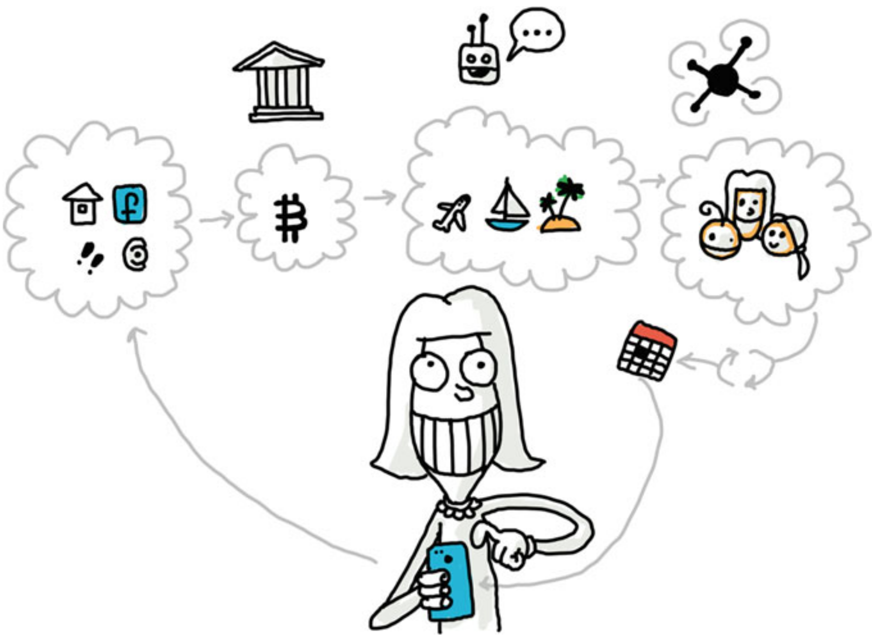

Fig. 10 ©Brian Subirana. All rights reserved

Her IoT negotiation agent then updates her on her new health achievements after her intense week of sport: lower blood pressure, more stable blood glucose response, and a higher daily average of activity. Due to her latest performance achievements, her life and health insurances automatically become cheaper for the coming month. Instantly, her standing balance on her bank account is updated (Subirana and Bain 2006).

Before Dr. Brown settles into bed, the IoT negotiation agent re-emerges to politely suggest that now would be the optimum time to plan her training sessions for the coming week. Her friend Alex requested a tennis match on Tuesday, her yoga class has an available slot on Thursday, and her basketball team has requested her presence on Saturday for their upcoming home game. She agrees and the negotiation agent updates all calendars and requests and pre-books the community self-driving car for an express journey to her game. As she lies down, Dr. Brown is pleased to learn that her family has overtaken their closest friends in overall exercise and activity rates.

12 Conclusion

It can be expected from the impossible sports described that new technologies will play a key role in advancing the future of sports. As brain-machine interfaces, AR, and VR mature, a new generation of increasingly digital immersive experiences will bridge the physical and digital realms for a more enriched and dynamic form of sports. The integration of low-power sensors combined with advanced storage and networks will make it possible to capture, store, and compile more data from humans and cities than ever before, enabling AI to provide personalized sports experiences shaped on preferences, ability, location, and time. Hopefully, the merging of health data and blockchain technologies linked to government and insurance will reward healthy habits and hence incentivize a more active society.

However, for these exciting innovations to impact sports and society in a positive manner numerous hurdles will have to be overcome. Considerations must be taken as to how these powerful technologies should be designed and implemented to ensure that they are molded in a safe, fair, and sustainable manner. It is important that new AR and VR applications are designed in a way that merge the physical and digital worlds, rather than further disconnect society from reality. The ethical implications of using animal-machine interfaces to bring "intelligence" to non-human life forms must be acknowledged and incorporated into products that protect abuse of the technology. Finally, as drones and vehicles gain autonomy and data from any event and interaction is captured, it is essential to create secure software systems that protect themselves from malicious hacking and democratize personal data. In an era where innovation is moving at a faster pace than legislation, tech companies should think about the footprint their products will leave on society and take responsibility to design them in ways that impact it positively.

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Garcia Jordi Laguarta an electronic and information engineer, is a researcher at the Auto-ID lab of Massachusetts Institute of Technology. His research is focused on how the digital and information revolutions can be leveraged to impact human health and create a sustainable environment. Prior to work at MIT, he worked at Nutrino Health and InAGlobe Edu. In his free time, he can be found playing sports like soccer, basketball, and tennis or skiing and surfing. His chapter on impossible sports, sits at the intersection of his two passions—sports and new technologies.

Beyond 2030: What Sports Will Look like for the Athletes, Consumers, and Managers

Sascha L. Schmidt and Katsume Stoneham

Abstract

In this chapter, Schmidt and Stoneham look beyond the short- and mid-term impact of technology on sport through the eyes of the athlete, consumer, and manager. Combining the predictions offered by the authors of *21st-Century Sports: How Technologies Will Change Sports in the Digital Age* and their own findings, they present what sports will look like in the next thirty years. In the end, they dare to peek beyond the thirty-year mark, offering hope and a bit of guidance for the beyond.

In this book, we offer a glimpse of the future of sports in the twenty-first century and discuss technology-driven opportunities and threats we may face. In Chinese, the character for opportunity and crisis is the same. This also holds true in the world of sports. Whether it is artificial intelligence, robotics, or the internet of things, a technology offers incredible opportunities while posing challenges, for example, if used without proper security. By introducing technology, athletes, consumers, and managers invite both opportunity and crisis into their lives. Looking at emerging technologies, we try not to exaggerate their importance for sports, present, and future. Nor do we try to overly simplify what athletes, entrepreneurs, and innovators should do to cope with them. Rather, we explore and analyze the effects of technologically induced change processes in sports with the goal of providing some direction through our authors' predictions.

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1 Sports Industry Outlook 2030–2050

In this chapter, we aim to think beyond the short- and medium-term and paint a picture of the sports industry from 2030 to 2050. Our purpose is to increase the reaction potential and to stimulate thought, shift perspective, and make our mindset more elastic by consequence. The images we create here can serve as tools for conscious dealing with uncertainty about the future.

Whatever the future of sports might hold beyond 2030, what is certain is the ubiquity of data. Facilitated by progress in sensing and motion-tracking, advances in data collection and analysis will play a part in every technological advancement going forward. The gear, training, coaching, playing, watching, and betting on sports will all be "smarter" and will further sophisticate the competition between people, between machines, between cyborgs, or as a mixed form.

What the consequences will be for athletes, consumers, and managers in sport is, of course, difficult to predict. It is also not necessary for the developments discussed to become reality. They will, through contemplation, contribute to the ability to stimulate strategic discussions, challenge existing mental models, and improve learning and innovation. We all want to better understand the new age we are entering and need an antenna for what might come and where we might go.

1.1 Athlete After 2030

Traditionally, sport is competition between human athletes. This can be an individual sport or a team sport, but there are always two or more athletes or teams competing. Athletes always stand at the beginning of the value chain. Without the athlete, there would be no sporting competition, teams, clubs, or leagues. Without the athlete, suppliers would have no one to equip, coaches no one to train, and agencies no one to market. We imagine that there will be five categories of athletes in the future likely defined by the rules of a sport: (1) Able-bodied, unassisted athletes, (2) athletes assisted by technology, (3) robot athletes, (4) mental athletes, and (5) virtual athletes.

1.1.1 Able-Bodied, Unassisted Athletes

The first category of athletes—able-bodied and unassisted—will most probably compete in "purist" sport, in which athletes compete according to rules not unlike the ones we have now. For example, two players compete against each other on a physical tennis court according to the official rules of a classic tennis match. But even this category of athletes will be different from the ones we know today. To start, the athlete of the future will have ever-optimized training. For example, ten years from now, extensive data and new capabilities will allow training against "super-human" artificial intelligence replays (Siegel & Morris in Sect. 2), practicing flow state (Bartl & Füller in Sect. 3), endless scenario runs using digital twins (Chase in Sect. 3). Training against "virtual ghosts" (Siegel & Morris in Sect. 2) or against human form-factor robots trained to play like competitors might also be possible in the 2040s and 2050s (Siegel & Morris in Sect. 2).

Even if not used in "pure" matches, practice sessions could soon include special contact lenses that display real-time performance feedback (Siegel & Morris in Sect. 2) and synaptic and biochemical data on the athlete's health and mood could be transmitted by implanted or swallowed microprocessors. Also, diet will be further optimized: Beiderbeck et al., for example, propose in Sect.7 that athletes in 2030 will eat 3D-printed food.

Beyond being good at sport, the athlete of the future will need a myriad of data and technology skills to succeed. To control, use, and analyze their own playing data, and optimize training, data will be the guiding force. Without a strong grasp on what it all means, they will leave opportunity, and even fame and money, on the table.

What will also change in the future of athletes, is the ability to preempt, diagnose, and treat injuries at levels unknown today. It will not take long until medics instantly detect athletes' injuries (Siegel & Morris in Sect. 2). Major advances in personalized regenerative medicine will likely appear in the 2040 s with robot-assisted surgery and physical therapy (Siegel & Morris in Sect. 2). Knee injuries will be repaired by local injection of our own intracellular vesicles from stem cells (Hutmacher in Sect. 2). No longer will a torn tendon mean a weaker, more painful knee for life, and/or many surgeries with long recovery times. Instead, tendons—and maybe other injured body parts—will essentially regenerate. Beyond 2050, it is even conceivable that robots independently rescue injured athletes from dangerous terrain, for example, and be able to treat them (Siegel & Morris in Sect. 2).

1.1.2 Athletes Assisted by Technology

Next to the traditional human athlete, a new category of athlete—those assisted by technology—is likely to emerge. We believe that this category will include able-bodied and formerly handicapped athletes and that they will perform at a higher level than the unassisted athletes—more like a cyborg, with computerized body parts like human-controlled robotic prostheses (Siegel & Morris in Sect. 2). Mixed sports teams may then be formed with a new system whereby athletes are categorized by type and number of body modifications. If cyborgs compete against each other in direct competition, it promises more spectacle and possibly even more excitement than a duel between unassisted people. In a tennis match, with traditional rules or not, it is conceivable that cyborgs will be much more persistent than humans so that much longer rallies could be played. It is also conceivable that high-tech prostheses will significantly increase the power and precision of their strokes.

1.1.3 Robot Athletes

When cyborgs will have mastered challenging team sports that require interaction with each other is hard to tell. Much sooner, humanoid robots in sports will serve as sparring partners to humans—controlled via brainwave interface or gaze-based systems (Siegel & Morris in Sect. 2)—or as trainers. Eventually, we will also have robots in competition with other robots. For instance, in a robot football league, robot teams will play football against other robot teams. By 2050, there might even be the watershed event that was proposed by a community of robot developers: a team of humanoid robots defeats the reigning human football world champions (Kirchner in Sect. 2). Or, in our wilder imagination, on one side of the tennis court there can be a human being or cyborg and on the other side there can be a humanoid robot, a so-called mixed competition.

1.1.4 Mental Athletes

We already observe the rise of the mental or intellectual athlete, the third category of athlete, in memory and mental calculation contests. Mental competitive sports will only grow and differentiate as the competitive gaming industry develops. For example, when two players professionally compete against each other on a gaming console, we know this today as esports. Mental athletes have a different skillset to traditional athletes. For instance, esports professionals have superior skills in terms of perceptiveness and reaction speed. They can already make up to eight decisions per second, i.e. up to 480 decisions per minute. To achieve this, they invest several hours every day in motor, mental, and endurance training. While intellectual sports already exist, brain research could develop completely different techniques still unimaginable today. Perhaps, in the distant future, there will be completely new (virtual) intelligence competitions between humans and between humans and machines in as yet unknown thinking disciplines.

1.1.5 Virtual Athlete

The final category of athlete has yet to emerge because the sport or technology has not yet appeared. For example, with artificial intelligence we know that digital twins and endless scenario runs are possible; some or even all of these could be turned into new sports. It is easy to imagine an endless game of battling digital twins—tiger versus lion, Jim versus Steve, Maradona versus Messi, and more—facilitated by devices like a helmet with retina projection (Siegel & Morris in Sect. 2). Or with holograms created and controlled by software solutions or algorithms, tennis matches between human-like holograms could also take place. The skills required for these new sports will be distinct from other categories.

1.2 Consumer After 2030

The most powerful stakeholder in professional sports is, of course, the consumer. If new technologies in sports or new sports are accepted depends ultimately on whether they serve important consumer needs. For this reason, we predict that the power of consumers will grow. What the consumer wants to see in the future will determine what professional sports are performed and in which shape and form. The consumer will also likely play a greater role in the outcome of some sporting events. Harbingers for this development are initiatives like the Fan-Controlled

Football League (FCFL),[1] a real-world sports league where the fans are fully in charge. Via an interactive video overlay on Twitch, fans call American football plays in real time; the outcome of each fan vote is relayed to the quarterback and executed on the field. In addition to play calling, fans can act as general manager in the FCFL, allowing them to determine each team's name, logo, coach, and even the players that make the roster via a fan-run draft. The FAN Token—a newly developed cryptocurrency—serves as the digital currency of the league and a tool for ranking the voting power of fans (Heitner, 2017). Similar to what FCFL does in fantasy sports, fans will be soon able to buy into their favorite sport team's success by acquiring rights to cash flows from, e.g. prize money. Shares can be managed through blockchain with ownership defined by smart contracts and money distributed via cryptocurrency (Khaund in Sect. 3).

In the distant future, it is conceivable for spectators to not only steer but to directly influence the performance of an athlete. For example, in the fifth set of a tennis match, additional powers could be unlocked via nanobots in the blood of players to keep the game exciting. Or spectators could use spontaneous surveys to elect which player, humanoid robot, or hologram will be the next to join the game. This is already practiced in Formula E, where spectators can vote live and give certain drivers extra power boosts on the track.

There is also potential for the consumer to get closer to or even into the action. The same technologies that enable cyborgs or the physical enhancement of professional athletes could elevate the occasional fan to join a tournament or match. Augmented, virtual, and extended reality promises to bring a more integrated participatory experience to support spectatorship, which means spectators need not simply sit and watch but can actively participate through their own physical activity (Miah et al. in Sect. 4; Pirker in Sect. 4). Imagine, as an every-man, being chosen to join the Wimbledon tournament, suited up with special equipment, and having a real shot at defeating an elite athlete in front of thousands (even millions) of fans. Or, after the tournament is played, being able to take on a robot or hologram of a player from the tournament—practicing an exact backhand or returning what was the winning serve of a match.

Beyond direct intervention, there will be no better time to consume sports. At home or on the go, artificial intelligence "will automatically choose or merge camera views based on preferences, historic data, and event analysis with procedurally generated commentary" (Siegel & Morris in Sect. 2). Virtual reality will enable fans to watch their favorite sport from the best seats in the stadium and to bounce to different perspectives at the touch of a button. For a more social experience for fans who live far from a team's stadium, Shields and Rein predict satellite stadiums to watch virtual games (in Sect. 4). Chase assumes that, if we live close enough, we will go to the home stadium even when our team is away and watch the game with virtual reality headsets (in Sect. 3).

With artificial intelligence assisted 3D-printing, fans will also be able to have exactly the sports equipment of the athletes they admire. According to Beiderbeck,

[1]See www.fcfl.io.

et al., ten percent of sports footwear will be fabricated in this manner by 2030 (in Sect. 7). That means that all professional teams, most elite athletes, and those with deeper pockets can expect perfectly modeled equipment.

1.3 Manager (of Sports Business) After 2030

Finally, management must take into account the interests of athletes and consumers to get the most out of the sport. Enforced by new technology, not only the management of associations, leagues, clubs, and teams, but the management of events, venues, facilities, ticketing platforms, marketplaces, etc. will change. When new kinds of sportsmen emerge, new challenges are presented. For instance, a tournament director for an international tennis tournament needs to negotiate participation premiums with the manager of Roger Federer's grandson, cyborgs, holograms, or creators of said holograms, and even owners of humanoid robots. This may also mean organizing multiple events by athlete category, simultaneously, or in series.

Managers will also need to organize the increasingly complex transportation options, security, and even more physical space—in case we still have physical stadiums as we know them, today. In this case, Shields, and Rein, for example, envision passenger drones that transport people to stadium events (in Sect. 4). To accommodate these and other traditional forms of transport, will require at least, in part, stadium redesign. In such a scenario, it is also likely that managers will have more physical stadiums to manage. Satellite stadiums to allow more fans to watch games with a better atmosphere and virtual viewing aids, also predicted by Shields and Rein, will likely become popular in the 2030s (in Sect. 4). Imagine directing traffic in the airspace above Wimbledon, while maintaining security for Serena William's daughter, or providing convenient storage for drones while maintaining the ambiance of the event.

Not unlike future athletes, future managers will also be required to have an additional skill profile complete with greater ability to handle data. The dance of sport management between science and art will shift significantly towards science. For example, scouting based on pure intuition will likely no longer occur. Players will be assessed on endless metrics to determine their potential. And, the manager will have ever greater power with data on his or her side. With increased artificial intelligence capability, however, the scouting team of the manager may be slimmed. Instead of a staff of people required to take on mountains of data and information, "AI will be able to synthesize scouting reports, advanced game statistics, performance testing, training loads, injury reports, personality profiles, and more to predict how players might develop and whose talents they might mimic by modeling their potential development" (Chase in Sect. 3).

Beyond the athlete and team management, sport governance and officiating will also change to accommodate and rule on technologies as they emerge. For example, governing bodies need to determine the role ground-based and aerial robotic referees and automated refereeing systems should play in which sports (Siegel & Morris in Sect. 2). It will be increasingly difficult to rule on and regulate enhancements offered by technologies and define boundary conditions for their use, particularly when considering the industry of sport and how reliant it is on fairness. A guaranteed outcome is unacceptable. Everyone must have the chance to win. As a result, skin suits or performance-enhancing drugs in “pure sport” are ruled as unfair. But with new categories of athletes may also come new rules. For example, performance enhancement by drug or other method that will undoubtably accompany other medical progress like injury repair and prevention, may be ruled “acceptable” for some or all categories of athletes. If this occurs, doping control in major sports could be abolished while medications that improve athletic performance would be allowed. Before competition, athletes would only be checked to ensure that no electric muscle stimulators or boosting implants, for example, are being used.

As long as everyone follows the same rules, and it may be that there are different categories of rules, we make no comment on whether it is correct or better sport. With different categories of athletes and new sports, the rules will certainly take up more time. International sports bodies like the Olympic Committee, the FIFA, and UEFA, amongst others, will have increasingly complex categories and rulings.

2 And Beyond…

Our present is shrinking—from perception to lived realization—and time periods are getting shorter and shorter (Opaschowski, 2013). The future comes quickly. It consists of rapidly accelerating technology and does not wait for us. We are on the cusp of a dramatically different sports world brought on by technology that will push the boundaries of what is possible in sports and build a different future. Reaping the rewards of progress in depends on finding ways to race with technology rather than racing against it. “Ultimately, those who embrace new technologies will be the ones who benefit most” (Rodney Brooks, CTO Rethink Robotics cited in Brynjolfsson & McAfee, 2014).

However, it is still up to us whether technologies in the future improve or undermine our sports. While we did not focus on the ethical quandaries presented by the use of technologies—we’ve left that to our authors, ethicists, and philosophers—there are limits to the technologies acceptable for sports. Touched on by our author’s—Chase, Siegel and Rein, and Torgler, in particular—sport outcomes must remain uncertain. Any technology that removes this element would lose the interest of the spectator. We doubt that events that pair humans against robots, if the robots are assured to win, will be interesting after the shine of spectacle has dulled. Instead, we still want there to be a possibility that the underdog, like the oft-cited Oakland A’s, might win against the powerhouse New York Yankees.

We explored the development of technology and sports until 2050 (Fig. 1). Not all our considerations will become reality, even if they might become technically feasible. Therefore, we are not concerned with the accuracy of the future images of sport we paint, but with what they trigger in the reader. We are striving to invent the future of sport ourselves, instead of just predicting it. When all is said and done, the

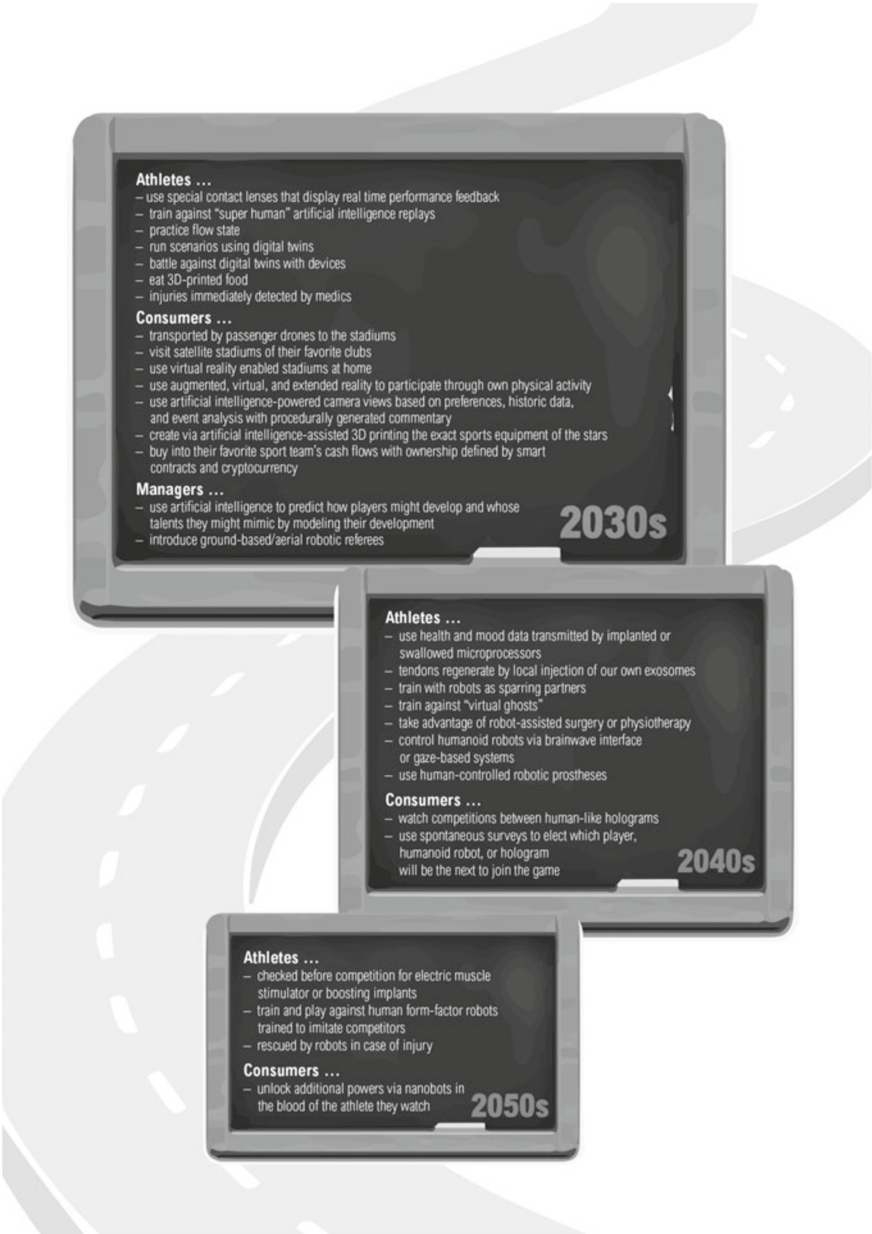

Fig. 1 Technology impact by decade

future of sports is what athletes, consumers, and managers make of it. With all the opportunities and crises ahead of us, we are optimistic that the best is still to come!

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